Gardening with BIOCHAR

SUPERCHARGE YOUR SOIL with BIOACTIVATED CHARCOAL

- Grow Healthier Plants
- Create Nutrient-Rich Soil
- Increase Your Harvest

JEFF COX

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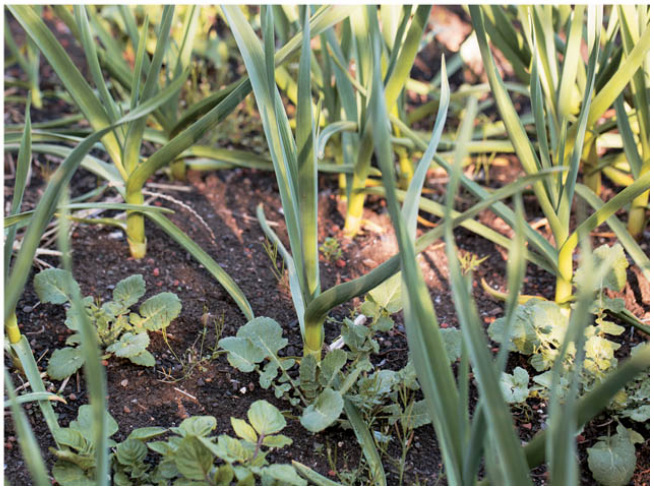

Contents

Preface: Supercharge Your Soil

Introduction: The Amazing Origins of Biochar

Chapter 1.
What is Biochar?

Chapter 2.
Making Biochar

Chapter 3.
Inoculate Your Biochar

Chapter 4.
Using Biochar in the Garden

Epilogue: The Promise of Biochar

Glossary

Bibliography

Metric Conversion Charts

Resources

Index

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Copyright

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PREFACE

supercharge your soil

I've seen some remarkable advances in crops and gardening over the years — supersweet corn, the two-handled U-bar digger — but nothing with the potential to revolutionize gardening and benefit the environment like biochar.

Biochar — wood and other organic matter that is roasted, not burned, to black charcoal — supports life in the soil, which is the key to healthy crops. Think of it as a way to supercharge your garden soil, not because it's nutrient-rich in its own right, but because it enhances the mechanical and biological processes that make for great gardens. As every savvy gardener knows, your garden is only as good as the soil it's growing in.

As an added benefit, biochar keeps carbon out of the atmosphere, where it would otherwise contribute to climate change. Because it's charcoal, biochar is mostly stable carbon — it breaks down very, very slowly. As a result, the carbon is kept out of the atmosphere for a much longer period of time than if the original organic matter were left to decompose.

Although our Western culture has just discovered biochar in the last 20 years or so, people have been making and using it for thousands of years to turn poor soils into bountiful farms that supported whole civilizations. Despite the fact that our research into biochar is still in its infancy, we already know enough about its benefits that people around the world are beginning to create it and use it to improve their soils.

Organic gardeners will be pleased that biochar's use requires no chemicals, poisons, or artificial fertilizers. In fact, biochar is actually used in soil remediation and water cleansing projects around the world. It holds soil contaminants to its surfaces, keeping them from being taken up by plants.

So enjoy learning about this remarkable substance and what it can do for you. It's a simple and very effective way to bring your garden soil to its full health and growing potential. Let me just say that in my 50 years of gardening organically, my discovery of biochar and its benefits is the single most exciting and important development I've ever seen.

My guess is that after you read this book and start using biochar in your home garden, you'll agree.

— Jeff Cox

ABOVE: *Biochar increases nutrient uptake and enhances plant growth.*

INTRODUCTION

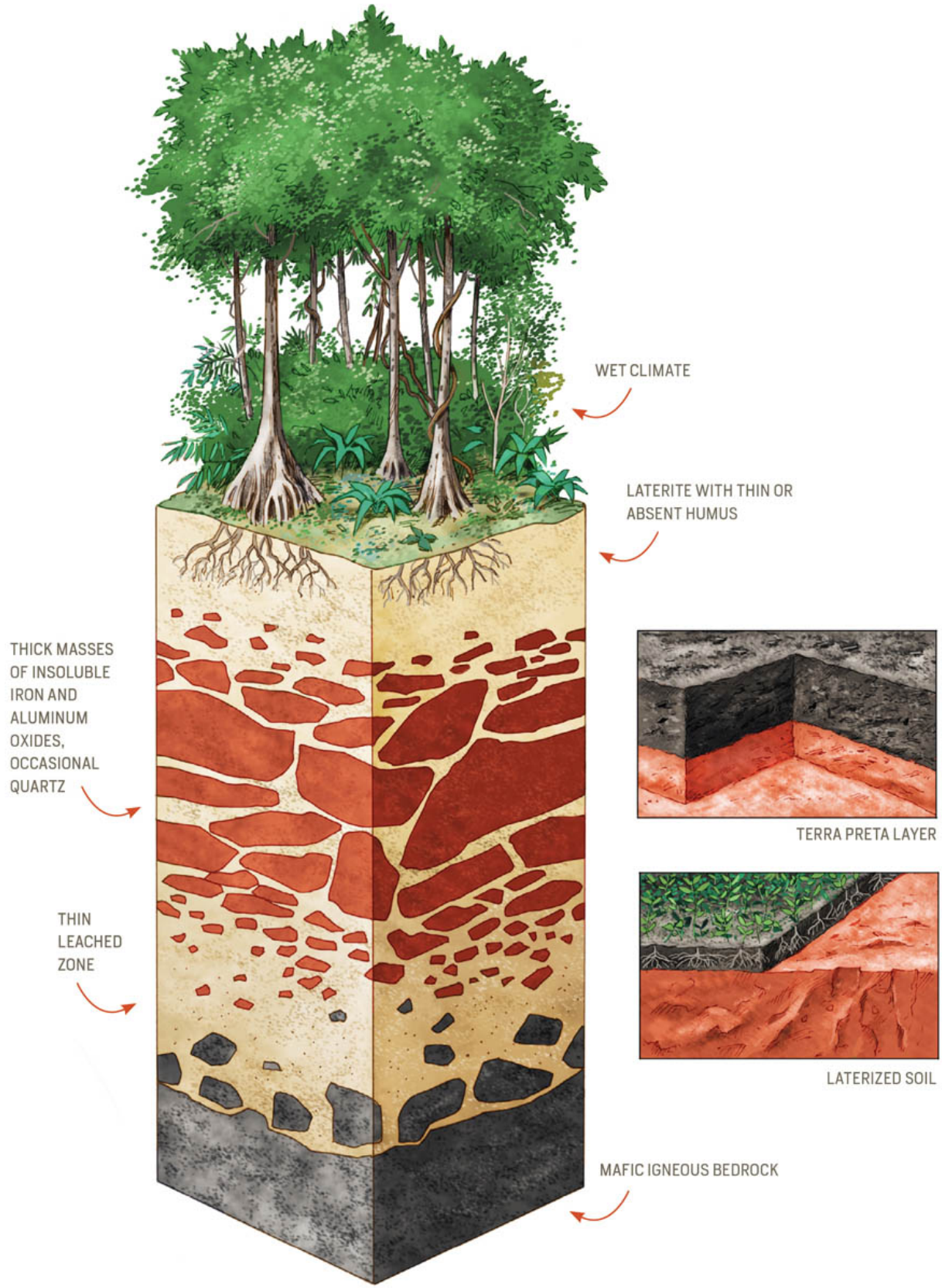
the amazing origins of **BIOCHAR**

Scampering along the branches of a ficus tree 150 feet above the Amazon rainforest floor, a howler monkey breaks off a leaf for a snack, but it falls from the monkey's hand and flutters downward. When the leaf reaches the steamy ground, it's immediately set upon by microbes, fungi, ants, and other ground-dwelling creatures that quickly skeletonize it and use its nutrients for food. These soil creatures' lives are short, and when they die, those soluble nutrients are released into the soil. Rain carries them down to the roots of the ficus, which **absorbs** them and hauls them aloft to create new growth and feed more howlers.

The heat and the moisture of the rainforest mean that almost all potential plant nutrients in the jungle are part of the living ecosystem that thrives in the tree canopies and understory plants. When people cut down the trees of the Amazon forest, there is a brief window of fertility before the soil turns hard as a rock (a process known as **laterization**). Removal of the trees to open up areas for gardening means fewer nutrients in the soil. So, people who live there often practice slash-and-burn agriculture: they cut down the trees, then burn them to clear the area, leaving the ash to fertilize the soil. But, when the soil laterizes after a season or two, it becomes incapable of supporting gardens and field crops, so the farmers move on to fresh forest and repeat the process.

But it wasn't always that way in the jungles of the Amazon basin. Far from it.

THE CONDITION OF AMAZONIAN SOILS IN THEIR NATURAL STATE


WET CLIMATE
LATERITE WITH THIN OR ABSENT HUMUS
THICK MASSES OF INSOLUBLE IRON AND ALUMINUM OXIDES, OCCASIONAL QUARTZ
THIN LEACHED ZONE
MAFIC IGNEOUS BEDROCK
TERRA PRETA LAYER
LATERIZED SOIL

farming before the time of slash-and-burn

Estimates are that human beings reached South America between 15,000 and 20,000 years ago. These were hunter-gatherers who colonized the western coastal lands from Colombia down to southernmost Chile, and eastward over the Andes to the high deserts, and farther east to the Amazon River basin. About 10,000 years ago, agriculture developed in settled societies in Asia, the Fertile Crescent of the Middle East, and then in Europe. It also developed in the Americas, where farming took unique forms among the indigenous people.

ABOVE: *Terra preta was first discovered in the Amazon River basin.*

While tribal confederacies and Native American nations like the Iroquois and Cherokee were developing sophisticated governments and Central American peoples were developing corn, people living in the Amazon basin and surrounding areas were learning how to farm the poor soils of the rainforest. They learned that recycling organic matter was one key element in improving their soils. Their middens contained food wastes, human and animal manures, bones, and lots of broken crockery. Returning organic waste to the land around their encampments helped improve the soil, but because the

material decomposed so quickly, soil amendment was a process that required a lot of labor and inputs in order to increase crop yields. They produced just enough food to sustain their population level.

Expansion began when the Amazon people added one more ingredient to the contents of their middens: a special kind of **pyrolyzed** charcoal that we now call biochar.

the discovery of biochar

When the farmers of the Amazon basin added biochar to decomposing organic matter, something amazing happened. Fields and gardens sprang to life. Over time, the poor soil of the Amazon became dark, porous, and extremely fertile. It's called *terra preta*, "black earth" in Portuguese.

Some archeologists cautiously estimate that between 450 BCE and 950 CE, natives of the Amazon basin and surrounding areas improved so much soil that this "black earth" covers an area the size of France. Others claim there's evidence that the Amazon landscape was not just wild jungle, but that parts were managed by humans for many millennia BCE and as late as 1250 CE.

With the discovery of pyrolyzed charcoal as a soil supplement, the food of the native peoples wasn't limited to whatever they could glean from the forest. This had a profound effect on the Amazon population. When people learned to improve soil fertility, populations grew because they could raise more food.

arrival of the europeans

With the arrival of the Spanish to South America, the world of the Amazonians changed drastically. Francisco de Orellana — who participated in the overthrow of the Inca Empire with his relative Francisco Pizarro — heard tales of a fabled city of gold called El Dorado to the east of Quito, Ecuador, where he was living. As a conquistador, he thought it would be a fine thing to find El Dorado and loot it of its gold and treasures. So he and a group of Spaniards set out in 1541 across the Andes and traveled eastward, down rivers, until they eventually became the first Europeans to discover the Amazon River. He made notes of his discoveries and reported densely populated regions along hundreds of miles of the river, all the way to its mouth at the Atlantic Ocean. He wrote that he found cities of 100,000 people or more, wide roads, bridges, and cleared agricultural land. Now we know his observations show that indigenous farming with biochar was fabulously successful.

For many years, historians thought that Orellana was exaggerating, but in the past 35 years, the extent of the terra preta soils confirms what Orellana wrote. Not only that, but in recent years, numerous geoglyphs — manmade landforms in the shape of circles, ovals, squares, and rectangles — have been found throughout the Amazon region. Although the native people there today have returned to the hunter-gatherer way of life and slash-and-burn methods, rather than the slash-and-biochar agriculture of their forebears, many of them carry on a hereditary aristocracy. Since such chiefdoms are almost unheard of in nomadic societies around the world, this

suggests that the native people of this region were once settled farmers with great cities and high rulers.

With the arrival of more Spaniards, most of the natives died of Eurasian diseases such as smallpox, to which they had no immunity. From five million native people in the 1450s, the population dwindled to less than a million by the late eighteenth century and stands around 200,000 people today. Ancient forms of government and settled agriculture were abandoned by those who survived the conquistadors. Set on the run, and pursued by disease and exploiters, they retreated deep into the jungle. Today, there are only a few pockets of native Amazonian people — and they do not have much, if any, contact with the outside world.

a new era for gardening

The immense extent of manmade terra preta soil shows just how vibrant the pre-Columbian civilizations were. And most amazing of all, those soils are still here; they haven't laterized or lost their fertility. They are as fertile today as when they were made many centuries ago, and they persist because the carbon is sequestered. A new era of gardening is here — and the fabled gold of El Dorado may actually be black and crumbly.

It is likely that the technique of pyrolyzing organic matter and incorporating it into farm fields arose among humans in more places than the Amazon basin. Archaeologists and anthropologists studied 177 sites in Africa — villages and

agricultural lands in northwest Liberia and Ghana — and discovered enriched soils known as “African black earths” that contain 200 to 300 percent more organic carbon than nearby soils and can support more intensive farming. These sites also contain 2 to 26 times greater amounts of pyrogenic carbon — that is, biochar. And there are more reports of rich soils with extra carbon in them from around the world, including in the Great Plains of North America.

ABOVE: *This two-foot-deep layer of terra preta was documented in 2007 on a papaya plantation in Costa do Laranjal, a settlement on the banks of the Rio Solimoes in Iranduba, near Manaus, Brazil.*

NOTES FROM THE FIELD

A CALIFORNIA WINERY BETS ON BIOCHAR

Founded by Randall Grahm in 1983, Bonny Doon Vineyard in Santa Cruz, California, is known for its quirky labels, eclectic mix of grapes, and humorous names — like its flagship wine, Le Cigare Volant (the flying cigar). Bonny Doon was one of the first California wineries to embrace Rhône varietals and is one of the few biodynamic vineyards in the United States.

Grahm first became interested in biochar as a potential strategy to enable the vineyard to dry-farm (farming without irrigation) in the low-rainfall region of San Juan Bautista. He began incorporating it into the vineyard's soils in 2015 on an experimental patch where he planted 10,000 new varieties of hybridized grapes to establish a new terroir and a new taste — something never experienced before in wine. Grahm is not one to do anything half-heartedly, so he went ahead and purchased eight shipping containers full of biochar.

"It's a terribly ambitious project," says Grahm, "but worth a try."

Grahm charged his biochar by making a 50-50 mixture of compost and biochar and added a small amount of granite rock powder for the minerals it contains. He then spread this mix at about 8 tons per acre on his San Juan

Bautista site, which has a wide range of soil types: mostly sandy loam, with some clay, some limestone, and granite. Once spread, he used a tractor to lightly turn it into the soil. Then he planted a cover crop (clover, alfalfa, or vetch) to add organic matter and nitrogen to the soil.

In addition to grapes, the land at Bonny Doon produces vegetables, fruit trees, and olives.

“When we first started our experiments with biochar, we used vegetables to test the results,” Grahm says. “We noticed one of the biggest differences was in the taste of our tomatoes. There was an extraordinary depth of flavor. We’re still just in the beginning stages with our vineyard crop. We’ve been very conservative with our water usage, and so far, the plants are thriving with minimal irrigation, producing high quality, extremely delicious fruit and oil. We’ve spread that 8 tons per acre on the entire acreage we eventually want to plant.”

ABOVE: *Randall Grahm is experimenting with biochar at Bonny Doon Vineyards*

CHAPTER 1

what is **BIOCHAR?**

We've known for years that plants communicate with one another through their roots and the networks of soil-borne fungi that colonize them. But scientists are only now discovering that those connections are just the tip of the iceberg. We may sit quietly and enjoy the peace of nature in our gardens and local woodlands, but above, around, and below us, the natural world is humming with almost infinite activity. Think of Manhattan Island made of living tissue. Truth be told, our gardens and landscapes share in the thunderous communications systems buzzing in their biology, especially in the webs of fungal mycelia that carry messages among plants.

The natural ecosystems facilitated by these communications systems are the key to a healthy soil, because they increase its biodiversity. The more life-forms, the more the food sources available are utilized, and the more complex and stronger is the web of life. The carbonized cellular structure in biochar, full of chambers and pockets, serves as a kind of apartment complex for a variety of soil microbes. They afford them protection from predators, plus spaces to fill with their metabolic products, substances that extract minerals and help create good soil structure.

ABOVE: *Biochar increases soil particle aggregation, creating friable, crumbly soil.*

what is this **STUFF?**

Biochar is pyrolyzed organic matter; that simply means it has been roasted at temperatures above 660°F (350°C) with very limited oxygen. Just about any organic matter — any plant or animal that was once alive — can be used as the raw material, also called **feedstock,** but plant material in general and wood

in particular is preferred. The term *biochar* for this soil amendment was coined by environmentalist Peter Read in 2005 because it's made from **biomass** — another term for the organic matter used to make it.

In pyrolysis, combustion is reduced by restricting airflow to the organic matter once it is actively burning. This can, for example, be achieved by loading the feedstock into an open-top, cone shaped pit and setting fire to its surface. As this top fire burns, it draws the air out of the material below it. Pyrolysis can also be achieved by firing feedstock in a nearly airtight oven such as a woodstove or Top Lit Up-Draft (TLUD) stove — or by placing the feedstock in an airtight container in the oven. The fire needs some air, but the operative part, the roasting, can be done completely anaerobically. Some biochar makers replace the air in their ovens with an inert gas, usually nitrogen, so no combustion can take place.

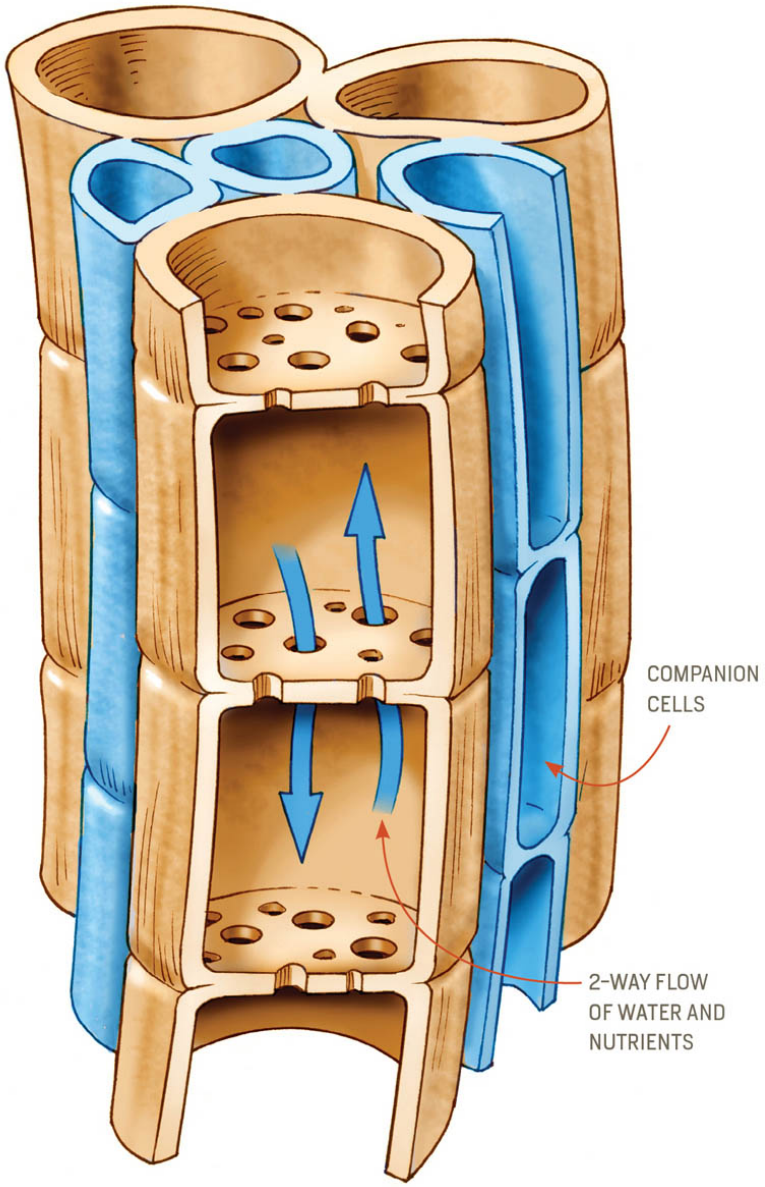
A STABLE CARBONIZED STRUCTURE

Heating the feedstock with very little air roasts it, rather than burns it, preserving the structure of the material down to the microscopic level. If you looked through a microscope, you'd see that a fragment of biochar made from wood is porous and consists of empty chambers. These chambers are the remnants of the **xylem** and **phloem** vessels that formed in the wood and leafy materials of the feedstock. (You might remember from your school days that xylem tubes channel water and nutrients taken up by plant roots and deliver them to the leaves, where photosynthesis happens. And phloem tubes carry organic

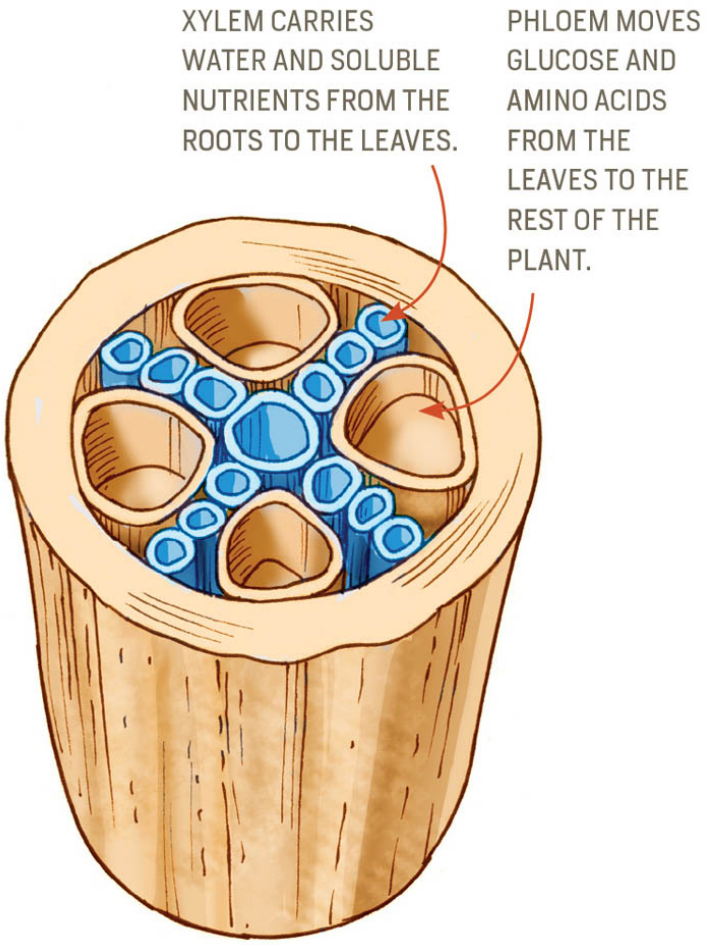
molecules and nutrients out to the growing parts of the plant, such as shoot tips, flowers, and fruit.) These tubular transport structures are filled with liquid in the living plant, but after pyrolysis, they're empty. These pockets serve a number of useful purposes in the soil.

In addition, biochar provides a stable source of carbon in the soil, which increases the ability of plants to take up nutrients from the soil. The carbon in biochar is a ring-shaped molecule that exhibits unusual persistence. It is very difficult to cause these molecules to break apart and react with other substances. Pyrolyzed biochar is only slowly degraded by microorganisms. A portion of the feedstock's carbon is given off as smoky gases during pyrolysis, and roughly 3 to 5 percent of the carbon is lost in the first few years after biochar is applied to soil, but the rest of the carbon in biochar stays put for much longer. That's why the terra preta soils of the Amazon are black with carbon thousands of years after being first created.

PHLOEM VESSEL



CROSS SECTION OF STEM AND ROOT


XYLEM CARRIES WATER AND SOLUBLE NUTRIENTS FROM THE ROOTS TO THE LEAVES.
PHLOEM MOVES GLUCOSE AND AMINO ACIDS FROM THE LEAVES TO THE REST OF THE PLANT.

ABOVE: *When biochar is made, the xylem and phloem in plant material carbonizes and retains its structure. These former transport channels then take on a new role: holding water and providing habitat for microorganisms.*

OTHER ATTRIBUTES

Some biochar fresh from the pyrolysis kiln will be **hydrophobic** — that is, it repels water. For it to function beneficially in the soil, it needs to be transformed into **hydrophilic** charcoal — so that it does not repel water. Biochar needs to be soaked in

water to become hydrophilic, but it also needs to be inoculated with microorganisms. This process can be as simple as mixing the biochar with **compost** tea or worm castings, which also suffuse it with nutrients. Fresh biochar typically has a high pH, and in many instances can be used a bit like ground limestone or hydrated lime to raise soil pH (more about soil pH later).

Biochar and Wood Vinegar

To produce biochar without releasing any greenhouse gases at all, the kiln or oven needs to be able to capture and store the gases. In commercial biochar production, the gases released during pyrolysis are trapped, condensed, and burned to assist in the pyrolysis heating, while a fraction of them are condensed into what's called wood vinegar (an important coproduct of biochar that is highly regarded in Japanese horticulture and agriculture). Wood vinegar is purported to have a number of uses and benefits, including: reducing the need for fertilizers and pesticides, enhancing root growth, improving germination of seeds, increasing uptake of nutrients by roots, promoting better taste and higher sugars in fruits, increasing resistance to disease, controlling fungus, and speeding up composting. Wood vinegar is not much used or even found in the United States, but it seems to be something of a panacea in Asia and the antipodes.

the benefits of BIOCHAR

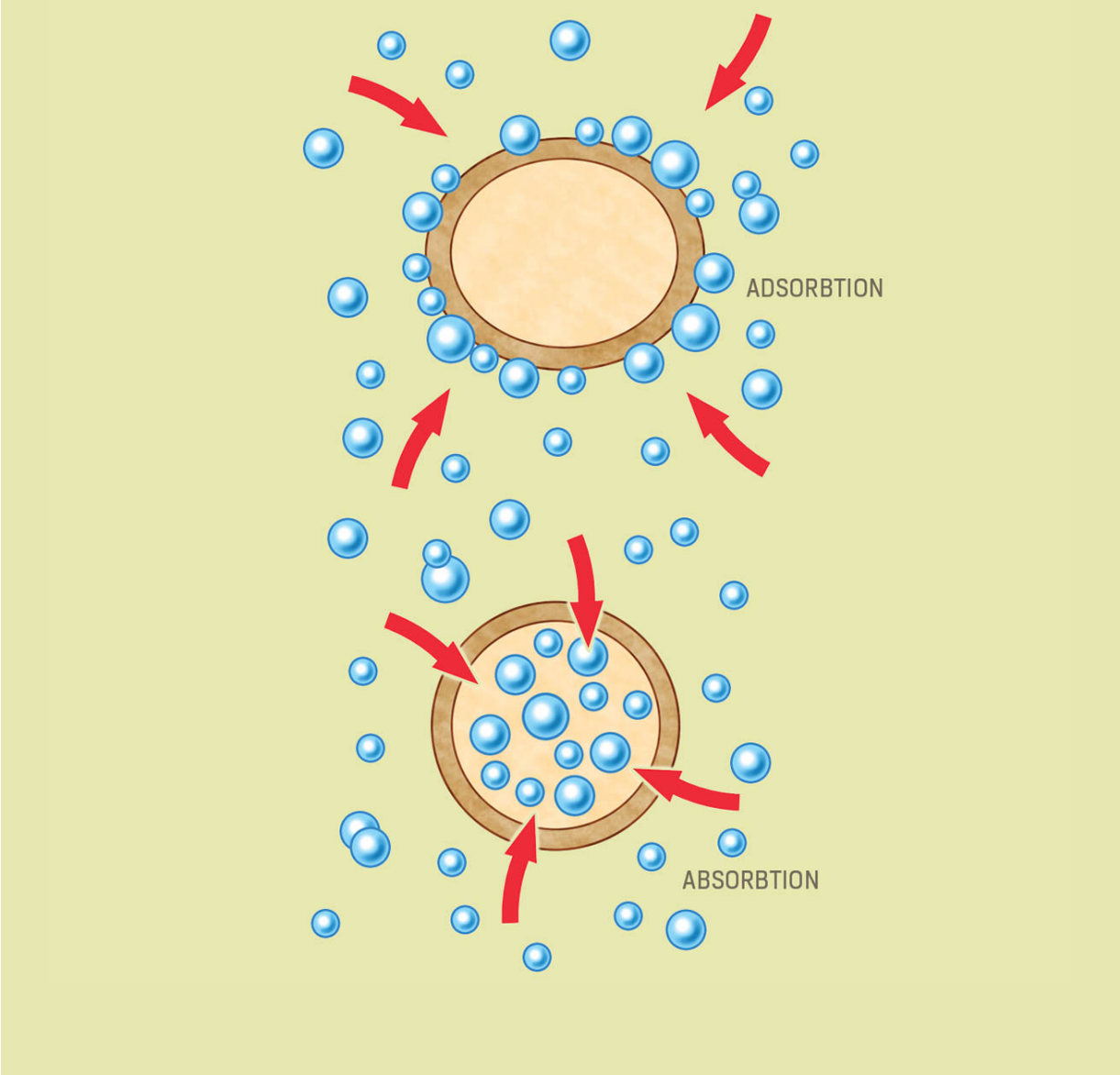
On the surface, it might be difficult to see how biochar could be beneficial for the soil. It isn't a nutrient or food source for microbes or plants. Soil-dwelling creatures like earthworms ingest it as they ingest the soil it's mixed with, and their innards grind the biochar particles to smaller sizes, but the biochar itself doesn't provide nutrients to the worms. Biochar doesn't dissolve in water. It doesn't degrade as quickly as uncharred organic matter. In fact, when archaeologists want to date their digs, they use charcoal for radiocarbon dating because carbon is so stable in the soil.

A HOUSING COMPLEX FOR MICROBES

So if biochar isn't a fertilizer, what is it? First of all, you can think of it as a housing complex for soil organisms. Among the empty phloem and xylem **tubules** are large spaces that once held living plant cells. All these internal rooms and spaces are **adsorbent**, holding water, oils, sugars, proteins, and other substances produced by the microbes that occupy the spaces. As in any ecosystem, there are predators that roam the soil, looking for microbes to eat. The spaces within biochar provide safe hiding places for the beneficial soil microbes that do so much of the work to feed and support the health of the plants with which they are growing.

Absorb and Adsorb

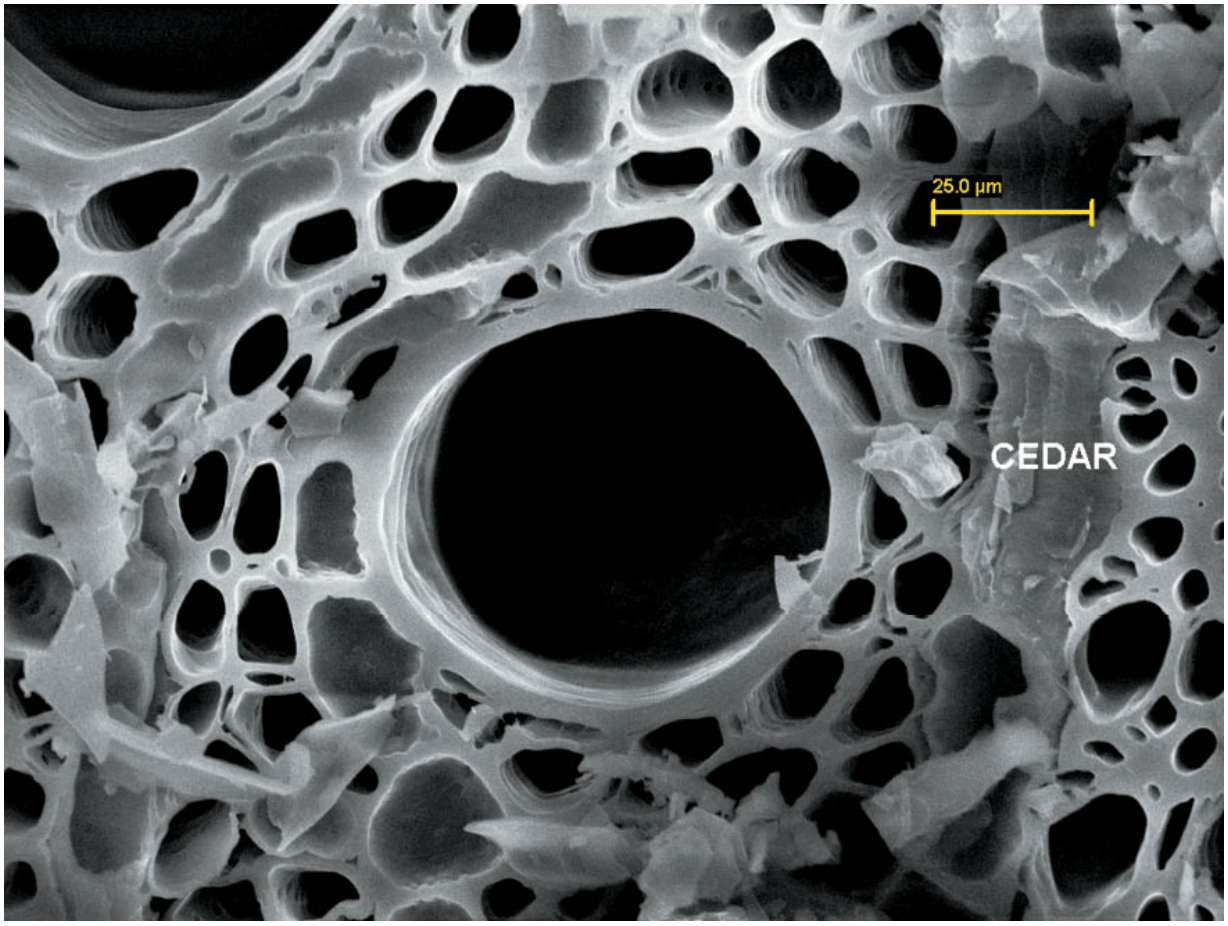
It's important to note the distinction between *absorb* and *adsorb*. When a substance absorbs another, it soaks it up the way a sponge absorbs water, or water absorbs carbon dioxide to form carbonic acid. To *adsorb* means to hold something on a surface. Because some biochar has an enormous surface area for its weight, it can adsorb large amounts of gases, especially poisonous ones. This is why gas mask filters are filled with charcoal. The gaseous molecules are held to the surfaces of charcoal by a physical surface tension, or by reacting with the carbon surface to form a layer of chemical compound.

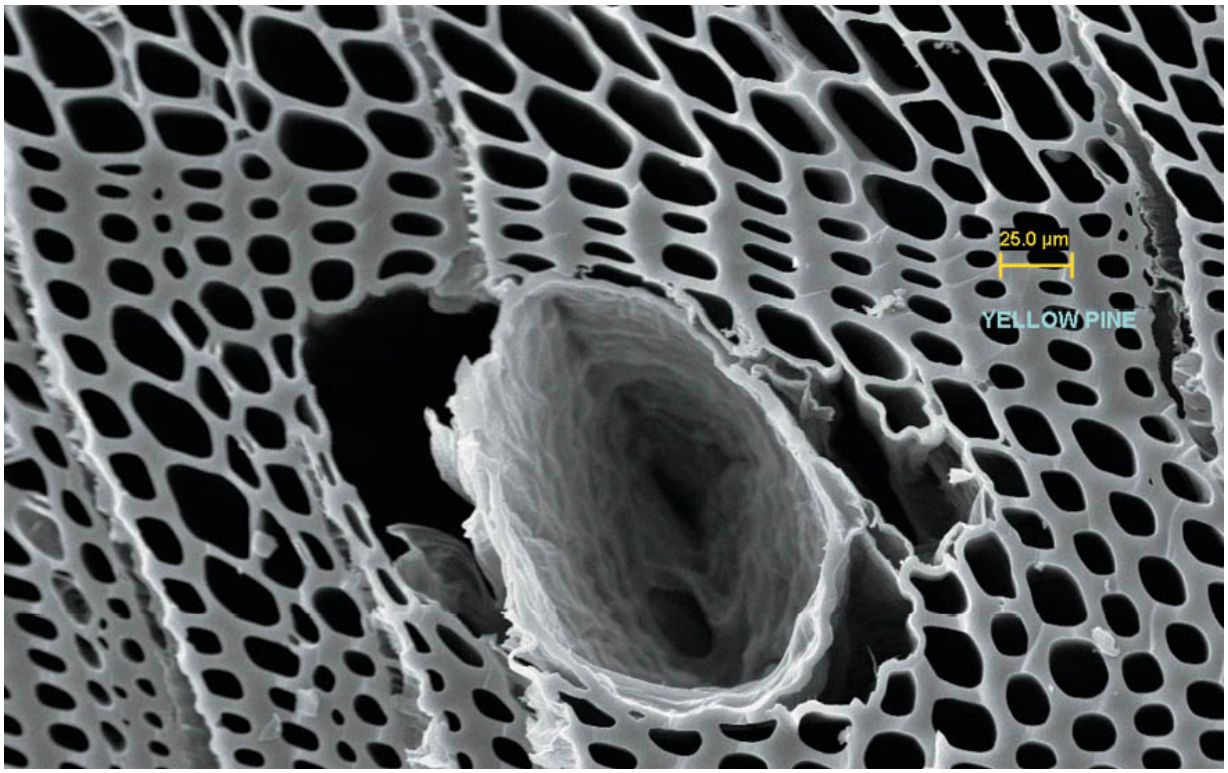


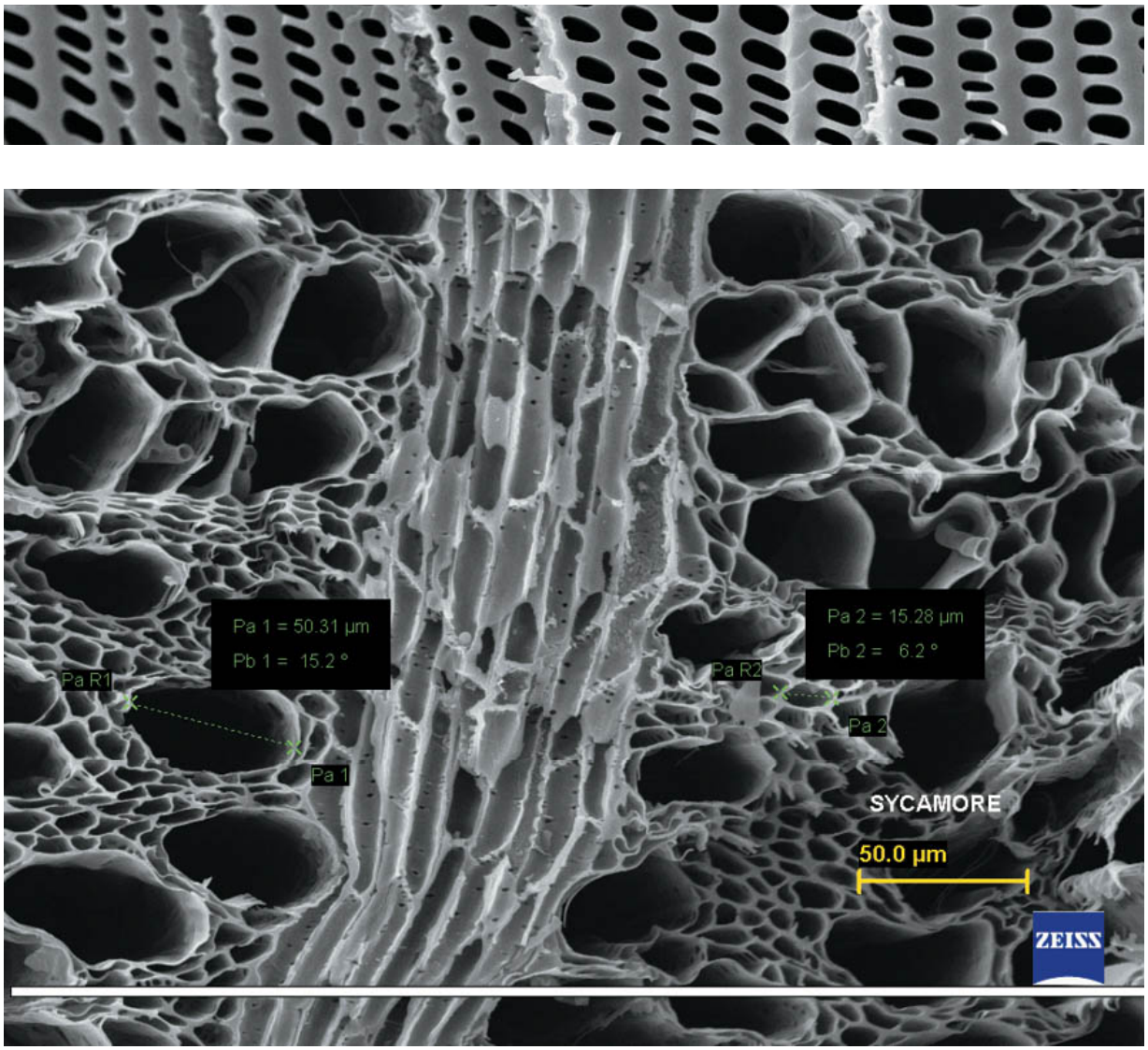
A RESERVOIR FOR WATER AND NUTRIENTS

Besides providing housing to soil creatures, biochar's tubules, when in the hydrophilic state, draw in water and nutrients through capillary action. The water is then metered out to plants as needed, giving biochar-amended soils a drought tolerance they may not otherwise have. The nutrients not only

feed plant roots but also feed the microbes living in the biochar housing complexes. The combined effect of better water-holding capacity and proliferation of soil life gives biochar-amended soils lightness and a natural fine tilth that plants love. For example, a poor soil deprived of organic matter can only absorb about ½ inch of rain before water begins to run off. Loading the soil with a biochar mix enables the soil to absorb 8 inches of rain before runoff begins.


25.0 µm
CEDAR


25.0 µm
YELLOW PINE



ABOVE: *These microscopic images of cedar, sycamore, and yellow pine biochar show how the cellular structure has been preserved.*

Comparing Types of Charcoal

ACTIVATED CHARCOAL

This form of charcoal can be impregnated with chemicals, then roasted (pyrolyzed) at a very high temperature in a sealed kiln that's filled with an inert gas like carbon dioxide, nitrogen, or argon to keep it away from oxygen. After a certain time, oxygen is flooded into the chamber and the gases trapped in the pores of the charcoal burn away at temperatures up to 2,192°F (1,200°C). In so doing, the escaping burning gases create micropores throughout the charcoal's surfaces, making a charcoal with an incredible amount of surface area: just 1 gram of activated charcoal has a surface area of 32,000 square feet. The enormous surface area allows activated charcoal to absorb or adsorb chemicals of all kinds, which is why it's used in cases of poisoning, to grab and hold the poison until the stomach can be pumped.

ABOVE: *activated charcoal*

CHARCOAL BRIQUETTES

These are made of finely chipped wood that's slowly charred in the presence of air, typically at 525 to 1,200°F (275 to 650°C), as it's being stirred in a large kiln. When it reaches the desired amount of burn, it's doused with water to quench the fire, and the resulting wet mass is pressed into briquette form by steel rollers. The pressed briquettes are then passed on a conveyor through a drying apparatus that heats them to 275°F (135°C) and dries them out. They complete their burn in your Weber.

ABOVE: *charcoal briquettes*

BIOCHAR

Biochar is plant or other organic material roasted in an oxygen-free or nearly oxygen-free process called pyrolysis at 662°F (350°C), typically a much cooler temperature than that used to make activated charcoal, and without regard to maximizing its flammability compared to wood for charcoal briquettes. This relatively low-temperature roasting preserves the structure of the feedstock's pores, which is all-important for biochar to do its work. It also removes volatile compounds, which are typically left behind in charcoal produced for fuel (a good reason not to use charcoal briquettes in place of biochar).

ABOVE: *biochar*

ABOVE: *Cucumbers and other members of the Cucurbitaceae grow well in biochar-amended soil.*

A BOOST FOR PLANTS' ABILITY TO TAKE UP NUTRIENTS

While the interior structure of biochar increases the water-holding capacity of the soil, the surface of biochar acts as a reservoir for nutrients. This is one of the most important benefits biochar offers plants.

Most biochar is carbon in its stable ring form, which captures photons, electrons, and a range of ions. Because it draws in photons and doesn't reflect them back, carbon appears black. Because biochar was once living plant tissue, it contains more than just carbon. It also contains minerals like magnesium, potassium, iron, and manganese — positively charged plant nutrients that are called **cations**. Because these elements and others in the biochar carry a positive charge, they are attracted to the negatively charged surfaces of the biochar. This activity isn't strong enough to form chemical bonds, where atoms share electrons to form compounds, but simply holds the minerals in a loose aggregation on or near the charged sites of the biochar. In other words, the positive ions are adsorbed by the biochar and held lightly there until needed to feed plant roots. This is called the **cation exchange capacity (CEC)** of the soil, and it has great importance for the way rich, organic, biochar-amended soils feed and support plants.

Often embedded in the carbon of the biochar are compounds that can react to create **anions,** negatively charged ions. One of the most important anions that feed plants is phosphate, and phosphorous can adhere to biochar's surfaces.

Both cations and some anions are taken from the soil solution (the soil's natural moisture) and held to the char's surfaces. This reduces the amount of nutrients that leach out of the soil during rains or by irrigation. Yet they are not held so tightly that they can't be moved. If you looked through a

microscope, you might see electrons shifting around on biochar's surfaces, jumping from atom to atom, into and out of the soil solution, following nature's orders for building plant tissue and creating food for microbes.

BIOCHAR = NUTRIENT STORAGE FACILITY

In this way, the biochar particles act as storage facilities for the cations that plants need to grow. Some of the nutrients stay in the water so they're available to plants, while excess nutrients gravitate to the charged surfaces of biochar, to be held there electrostatically until needed. As plants' feeder roots take the cations from the soil and the nutrients become depleted, the CEC calls for replenishment from the storage area of biochar.

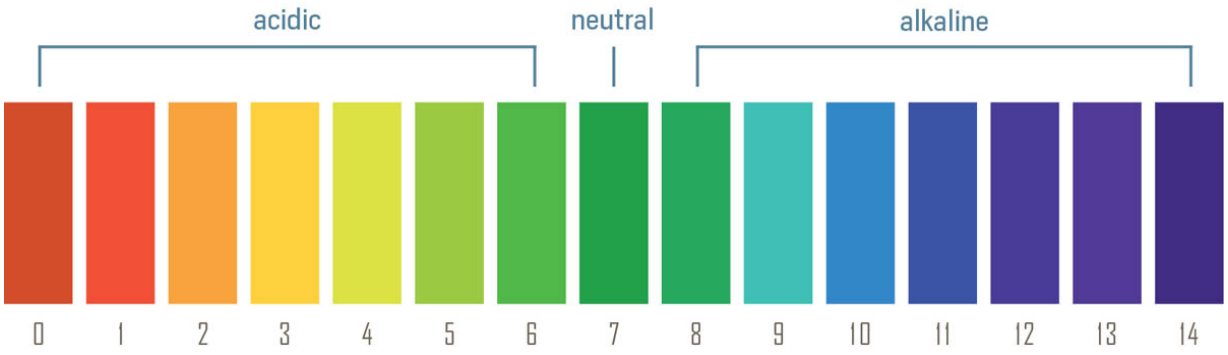
In other words, organic soils that contain biochar have a built-in mechanism for maintaining the proper balance of plant nutrients in the soil's moisture. Excess cations are warehoused on those negative surfaces. If there are too few cations, the warehouses yield some back. The CEC keeps the soil solution stocked with the nutrients plants need, in the amounts they need them, at the times they need them, and in the forms they like.

BE AWARE OF PH CHANGES

Changes in pH affect the cation exchange capacity of the soil. So it's important to know that biochar raises the pH of acid soils, making them more alkaline, and making nutrients less available for acid-loving plants. Gardeners must therefore use biochar in appropriate amounts. More is not necessarily better,

especially in soils that are rich in organic matter and that are already in the 6.5 pH range. Using biochar too liberally could raise the pH into the alkaline range, which could slow the growth of acid-loving plants such as blueberries and strawberries.

How much is too much? To avoid pushing the pH up, use just 1 pound of biochar spread over 10 square feet, or about 1 inch of inoculated biochar on the surface. This is a good ratio unless a soil is very acid, heavily compacted, and nearly devoid of soil life. In a very acid soil, biochar's ability to raise the pH will be beneficial. It will also help loosen compacted soils. And if properly prepared, biochar will promote microbial activity in a soil depleted of life. In such damaged soil, use 2 pounds over 10 square feet, or about 2 inches over the surface.



A Soil Supercharger

The power of biochar to increase the cation exchange capacity of soil was shown in a study done by researchers

at the University of Washington School of Environmental and Forest Sciences, where they tested the efficacy of biochar on ten organic farms on the San Juan Islands north of Seattle. Biochar produced from timber harvest residues in the area was added to the farms' soils in combination with poultry litter fertilizer. Then researchers planted dry beans, green beans, and cauliflower on all ten farms for comparison with similar plots fertilized without biochar. Here are the rather amazing results:

- Biochar increased total soil carbon by 32 to 33 percent over the control plots.
- Biochar increased the availability of ammonium fertilizer by 45 to 54 percent.
- Potentially mineralizable nitrogen went up by 48 to 110 percent. (This is the fraction of total nitrogen in soil that microorganisms may convert to plant-friendly forms over the growing season.)
- Phosphorus availability increased by 29 percent. This is significant because phosphorus is usually one of the scarcest major plant nutrients.
- Retention of nitrates, ammonium, and phosphorus in plants' root zones increased by 33 percent, 53 percent, and 39 percent, respectively. This means that biochar-amended soil helps hold nutrients in the root zone, so they aren't washed away by rain and don't escape as gas into the atmosphere.
- The availability of phosphorus, iron, magnesium, and zinc increased, which was reflected in the nutrient

concentration of dry beans. This shows that plants grown in biochar-amended soils offer better nutrition to those who eat the plants.

DECREASE GREENHOUSE GASES

Another benefit of adding biochar to your soil is that its carbon will not be released as quickly as greenhouse gas. If more carbon is stored in the soil, it reduces the amount present in the atmosphere and thus reduces global warming. The process of storing carbon in soil is called soil carbon sequestration. Because of its properties, biochar doesn't enter the chain of decomposition the way, say, decomposing cornstalks do. As the cornstalks decompose, some of the carbon is used to build the bodies of the soil microbes, worms, and other denizens of the earth that are doing the decomposition. This natural flux of carbon through decomposition ends up with a significant amount of the carbon being released as carbon dioxide — a greenhouse gas that contributes to climate change. If those cornstalks (or any other organic matter) are pyrolyzed, that very stable form of carbon will stay sequestered in the soil for centuries, and the emission of carbon dioxide can be reduced dramatically — by up to 90 percent.

ABOVE: *Biochar can increase the capacity of soil to sequester carbon and reduce the emission of some greenhouse gases.*

Biochar also reduces the formation and outgassing of nitrous oxide, another greenhouse gas. Nitrous oxide is formed by soil microbes converting nitrogen fertilizers into gas. Biochar,

however, slows soil respiration, adsorbs ammonium, and reduces the formation of nitrous oxide.

It is true that the combustion of any biomass — wood, straw, leaves, weeds, and so on — releases methane, a gas that's 20 times more potent than carbon dioxide as a greenhouse gas. But the way biochar is made by pyrolysis helps retard the emissions of methane. Biochar gasifiers burn off methane emissions as air is allowed into a combustion chamber atop the pyrolyzing feedstock. Dominic Woolf and colleagues, writing in *Nature Communications*, estimate that widespread biochar utilization can reduce methane emissions by 12 percent a year.

BUFFER THE EFFECTS OF TOXIC ELEMENTS

Biochar can reduce the toxic effects of heavy metals in soils and in some plants grown in those soils. In one study, copper, manganese, mercury, lead, cadmium, chromium, and zinc, as well as arsenic compounds, all became less bioavailable in green beans when the beans were grown in biochar-amended soils, compared to those grown in soils not amended with biochar. We've known for years that soils rich in organic matter can reduce the uptake of toxins into garden crops; biochar adds another level of protection for gardeners who may not know they have toxic heavy metals in their soil.

Every Bit of Biochar Makes a Difference

The more biochar makers we have on this planet, the more we can reduce the effects of global warming. Each year, terrestrial plants absorb 60.6 billion tons of carbon during photosynthesis. About the same amount cycles back into the atmosphere through plant respiration and decomposition. So any carbon that is taken out of that rapid photosynthetic cycle and is sequestered for centuries helps slow global warming and climate change. Of that 60.6 billion tons of carbon taken up by photosynthesis, about 10 percent becomes available to human activity either as waste, where it will decompose and exacerbate global warming, or as biochar or other products. Agricultural residues from the cultivation of corn, rice, barley, and wheat stalks; forestry residues such as branch and leaf litters and wood trimmings during lumber manufacture; and animal waste are all potential biochar. If all 6 billion tons of carbon (the 10 percent mentioned above) were put through pyrolysis, about 3 billion tons of biochar carbon would be made. And that would offset most of the 4.1 billion tons of carbon dioxide released into the atmosphere by human activities each year.

This is a tall order, for sure, but each of us can make a difference. If you are like most people, 2.86 pounds of your daily 4.3 pounds of waste is organic matter. If you already recycle your glass, metal, and plastic, you may want to recycle your organic waste into biochar, too.

biochar and the electron EXPRESSWAY

By now, we all recognize how important it is to have healthy, active microorganisms in the soil. Simply put, a robust network of microbes helps gardeners grow better plants. Recent research explains some of the science behind how biochar helps sustain these soil-dwelling critters. The short answer: the carbon in biochar dramatically increases the movement of electrons, which microorganisms need for pretty much everything they do.

MOBILE ELECTRONS = MORE MICROBIAL ACTIVITY

Electrons flow through the soil and facilitate chemical and biological processes using carbon pathways. Carbon-rich organic matter was thought to be the standard way electrons got around, but a new study shows that organic matter is actually a rather low-performing vehicle for electron transfers, compared to the way electrons zip around using biochar.

A recent paper published in *Nature Communications* and titled "Rapid Electron Transfer by the Carbon Matrix in Natural Pyrogenic Carbon" shows that biochar can directly transfer electrons more than three times faster than soil organic matter. Tianran Sun, one of the paper's authors, explains that "microorganisms need electrons for everything they do. For any living biological process, they need electrons." So electron transfers govern pretty much all chemical and biological activities of plants, and these transfers are essential to plant health and vitality, and biochar speeds up these transfers threefold.

BIOCHAR SPEEDS UP ELECTRON TRANSFER

Because electrons travel using carbon pathways, and biochar is almost pure carbon, biochar acts like an expressway. It speeds electrons on their way, but it also gathers them from distances of centimeters away, according to Johannes Lehmann, professor of soil science at Cornell University, in whose lab the study's work was done. And centimeters, to an electron, are like light-years. Images from this exciting discovery show plant root hairs growing directly into particles of biochar,

thirsty for those electrons that facilitate the natural processes in the soil that make for plant health.

Dr. Lehmann says, “There are forms of biochar that are conducting electrons much faster than we had appreciated, and for longer distances. Many processes rely on receiving or donating electrons, such as microbial activity and root activity.” Having access to biochar in the soil can thus be a real advantage for healthy plant growth. Soil organic matter does contain carbon, but it’s in a less structured form than biochar. The orderly carbon structures in biochar amps up the rate of electron transport. In other words, you can travel faster on a smooth highway than on a road filled with bumps and potholes.

ACTIVE ELECTRONS = MORE NITROGEN FOR PLANTS

You may already know that some plants — like peas, beans, and other legumes — can “fix” their own nitrogen. More accurately, it’s the nitrogen-fixing bacteria (called rhizobia) on their roots that do the work. Each kind of legume has a specific species of nitrogen-fixing bacteria that colonizes its roots, forms nodules, and makes nitrogen available for the plant. Because of its ability to speed up electron transfer, adding biochar to your soil makes rhizobia work better and produce more nitrogen for the plant.

In fact, electrons are centrally involved in the way nitrogen-fixing bacteria in the soil take nitrogen from the air and convert it to forms that plants can use — nitrates, nitrites, and

ammonia. Nitrogen (N) in the air exists in the form of a tightly bonded N_2 molecule — two nitrogen atoms locked together — which plants cannot use. The N_2 bond is one of the strongest molecular bonds in nature. It takes a lot of energy to split that N_2 molecule into two atoms of nitrogen. When we produce chemical nitrogen fertilizer, we use an extremely energy-intensive method called the Haber-Bosch process to split the bond and produce ammonia.

Amazingly, rhizobia that live in root nodules of legumes can also split nitrogen molecules, and so can some free-living soil bacteria. They split the molecule by producing an enzyme that contains a bit of the metal molybdenum. As a molecule of N_2 comes close to the enzyme, the molybdenum releases electrons that draw in the N_2 and hold it to the enzyme. Electron shifts cause the atoms of nitrogen to click apart. Each nitrogen atom then forms bonds with three hydrogen protons to make NH_3 — ammonia — or with four protons to make NH_4 — ammonium — and both are the basis for nitrogen fertilizer. The nitrogen atoms can also link up with oxygen atoms, forming NO_3 or NO_2, nitrate or nitrite respectively, two more powerful nitrogen fertilizers. More electrons are needed to replenish molybdenum's supply, and in biochar-enriched soil, they receive it quickly. The replenished enzyme then awaits the next N_2 molecule to grapple with. Electrons make the whole process possible.

Rhizobia in the Garden

If you plant a legume that's been inoculated with rhizobia, pull up the plant when it's mature and has finished fruiting: you'll see little lumps on its roots. Nick one open and you'll see what looks like pink flesh inside. This is a colony of nitrogen-fixing bacteria, taking nitrogen from the air and feeding it to your plants. It's all natural, it's just what your plants prefer, and it's free.

Why not just use chemical fertilizer like ammonium nitrate? Because the addition of chemical nitrogen causes the natural nitrogen-fixing bacteria in the soil to shut down. So you end up paying for energy-intensive and expensive nitrogen when you can easily take advantage of free nitrogen provided by naturally occurring soil bacteria.

CHAPTER 2

making BIOCHAR

Most gardeners have enough property to accumulate twigs, stalks, branches, and other organic matter, and these can be pyrolyzed into biochar. The gist of the process is to roast the feedstocks so that the volatile substances in the material turn to gas, which rises to a top zone where enough air is allowed in for these gases to burn. This reduces smoke, carbon monoxide, methane, and other problem gases. The only flame is at the top where the gases are burning. Down below, the feedstocks are glowing red as they pyrolyze. While the feedstocks are still charcoal and haven't burned to ash, they are quenched with water to stop the pyrolyzation. When the charcoal dries, it can be reduced to chunks or powder, as you wish. It is now biochar.

You can make biochar in a pit in the ground, if simplicity is your aim. But if production of enough biochar to get your garden soil cooking is what you're after, a simple biochar gasifier (such as the one on here) will be much more productive — and won't require you to dig out a pit. The TLUD (Top Lit Up-Draft) stove takes some fabrication, but it is state of the art for the home gardener who wants to make a significant amount of biochar, and I'm delighted to share it with you.

IMPORTANT SAFETY ITEMS

ABOVE: *steel-tined rake*

ABOVE: *welder's gloves*

ABOVE: *hose or bucket of water*

STAY SAFE!

Before making biochar at home, there are a few safety measures you should take to protect yourself and the surrounding environment. Be sure to call your local fire department to ask about your town's burn laws and obtain any necessary permits. Establish your burn site where you won't be

in danger of setting nearby trees or vegetation on fire. Make sure you have a hose with good water pressure that reaches all the way around the burn site. Fit the hose with a shut-off nozzle and close it. Make sure the water to the hose is turned on before you burn. Have a shovel and steel-tined rake handy and someone else to back you up for protection. If it's a windy day, postpone the burn and wait for a day with little wind.

Have a sturdy pair of gloves that will protect your hands from fire if you have to grab a piece of burning wood that rolls out of the fire. Work or garden gloves are not sufficient protection from the heat of burning wood or hot metal. Welder's gloves are more appropriate and are long enough to extend up the arms.

TYPES OF FEEDSTOCK

ABOVE: *softwood*

ABOVE: *wood chips*

ABOVE: *straw*

ABOVE: *hardwood*

ABOVE: *wood shavings*

choosing a FEEDSTOCK

Feedstock is the organic matter that you are going to roast. Different types of feedstock will create biochar with varying amounts of surface area and, therefore, different levels of cation exchange capacity. One study conducted in China showed that among biochars produced from wheat straw, cornstalks, and peanut shells, the corn biochar had the greatest ability to adsorb nitrogenous compounds, due primarily to its greater CEC.

Different feedstocks will also create biochar with different textures. Char from dense hardwoods is lumpy and solid, while char from softwoods is light and easily crushed to the size of rice grains, which is ideal. This is why softwood construction waste, such as pieces of 2×4s, is a good option for making biochar.

Char made from weeds or farm biomass — like straw, hay, cornstalks, seed husks, weeds, and other grassy, weedy debris — will crush in your hand to a fine powder that will disperse and vanish into soil. Such soft, fluffy, fine-textured char has good effects on soil structure and adsorption capacity. Be sure to wear a mask to avoid inhaling the dust; it has the same effect on the lungs as coal dust, the agent that causes black lung disease. Animal materials such as manure tend to be wet and don't work well, although if the manure is very dry, it could be okay as a small percentage of your feedstock.

SMALL, DRY WOOD

For the ideal feedstock, branches and tree limbs should be no more than 3 inches in diameter. The feedstock must be dry down to 10 percent moisture. Kiln-dried trimmings from sources such as carpenters and cabinet shops work extremely well as long as they're no more than 3 inches in the thickest dimension. Similarly, branches and limbs should have been dried under cover for at least a year. To test, bend the limb at a narrow point. It should break with a sharp crack, not bend and break softly.

Do not use green wood. It won't burn and will create enormous amounts of smoke; fresh wood chips have the added disadvantage of clumping together, smothering the fire, and creating a lot of smoke. (You'll want to create as little smoke as possible. It's a serious pollutant, producing carbon monoxide and more than 330 chemical compounds that become airborne particulates when exposed to cold air. Sixteen of those

compounds are carcinogenic. The particulates tend to be ultrafine and can be carried on the wind as far as 10 miles.)

One hundred pounds of wood will yield 10 to 20 pounds of biochar, depending on the moisture content and type of feedstock. Light or resinous woods like pine, poplar, or eucalyptus will yield less; hardwoods like oak will yield more.

ABOVE: *Collect dry wood; you'll need two to three times the amount of small kindling sticks to larger branches.*

ANALYSIS OF BIOCHAR BY VARIOUS FEEDSTOCKS

Here's a breakdown of the biochar properties and element content by selected feedstocks, all of which were pyrolyzed at 662°F (350°C). These tests were made using poultry litter and swine solids (pig manure). Animal manures are not recommended as feedstock for home gardeners. Such organic materials should be composted and returned to the soil to add to the soil's stocks of organic matter. The nitrogen in animal manures would otherwise be largely wasted, as it is either locked in the carbon structures and mineralizes extremely slowly or it volatilizes as N_2 gas — or even worse: nitrogen gases.

This chart shows that poultry litter is strongly alkaline and pine chips are strongly acid. Mixing them 50-50 produces biochar that's still strongly alkaline, 63 percent carbon, and 3.4 percent nitrogen — a good amount of nitrogen. That mixture also yields 14 milligrams of phosphorus per kilogram of biochar, and 41 milligrams of potassium per kilogram of biochar. Both are good amounts and are readily plant available, but at those levels, they might be best supplemented with compost.

FEEDSTOCK	pH	% CARBON	% NITROGEN	MG OF PHOSPHORUS / 1 KG BIOCHAR	MG OF POTASSIUM / 1 KG BOCHAR
Poultry litter	9.6	51	5.6	24	59
Pine chips	5.7	78	0.4	0.2	1.5
50% pine chips/ 50% poultry litter	9.1	63	3.4	14	41
80% pine chips/ 20% poultry litter	8.4	75	3.4	5	9
Swine solids	7.3	50	6.6	47	15
Switchgrass	6.4	75	0.6	0.4	1.5

Nature's Biochar

Natural wildfires produce a charcoal layer that has an adsorbing capacity similar to activated charcoal. After a wildfire, a new litter layer begins to accumulate on top of the charcoal layer. Water-soluble nutrients from the top litter layer filter down through the charcoal and into the unburned humus layer in the forest's topsoil. This is nature's way of rejuvenating soil after a fire, a natural path

to the terra preta soils of the Amazon. The charcoal layer supports microbial communities that have a higher growth rate than those in the unburned topsoil below. Although the charcoal induces changes in the makeup of the microbial communities in the humus, it doesn't reduce the amount of microbes.

Dried wood feedstock needs some prioritizing before use. Separate the types of wood into a main load of branches and logs that are 2 to 3 inches in diameter, and another load of sticks that are less than 2 inches in diameter. However large

your main load of bigger pieces of wood is, you'll need two to three times that amount of the smaller stuff. Be sure to have some extra tarps on hand so that if rain arrives, you can cover all your feedstock piles.

ABOVE: *Be sure your feedstock is dry and ready to burn.*

CONSIDER YOUR SOIL pH

When selecting a feedstock, you should consider the pH of your soil. The feedstock will affect biochar's ability to change the pH

of your soil. For instance, if your base soil is at a good pH (6.0 to 6.5), you'll want a biochar that won't have a significant effect on the pH. As a rule, biochar made from softwoods and dried forbs will have only a slight effect on pH, raising it a fraction of a point. On the other hand, biochar made from hardwoods such as oak and maple, and from grassy material like cornstalks, will have a greater effect on pH, raising it toward the alkaline side. If your soil is very acid and you want to sweeten it, hardwood-derived biochar is an efficient way to do it.

making biochar in
A BURN PIT

A burn pit is simply a conical hole in the ground. The conical shape pulls air up from the narrow point in the bottom of the

hole, evacuating oxygen from the feedstock. Free access to air at the top allows the fire to burn the gases being released from the pyrolyzing feedstock below. This helps keep down smoke and noxious gases by burning them off, but it's less effective than making biochar in a TLUD.

1. TEST YOUR SOIL DRAINAGE

If you'd like to build a permanent burn pit for making biochar, you'll first need to determine how well your soil drains water; if you have clay soil that holds water, you may end up with a stagnant swamp over time. To test your drainage, perform a perc test: Dig a small 1-foot-deep hole in the ground and fill it with water from the hose. After it drains, fill it again. This second filling should have completely drained out within an hour. If it does, then your soil percolates well and your fire pit won't fill up with rainwater. If it doesn't drain within an hour, consider building a cooker instead.

ABOVE: *If you want to make biochar in a pit, you need soil that drains relatively well.*

Make a Burn Pile on Bare Ground

Rather than dig a pit, you could, instead, build the burn pile on the bare ground, which is easier than digging into the earth. However, the biochar won't be as high in quality

because the feedstock will be exposed to a lot of air. Not only that, but, just as you would for a fire pit, you need your local fire department's permission for open burns on bare ground. Sparks can float away and set nearby brush on fire. Open burns can produce a lot of smoke. If you must burn on open bare ground, follow the safety rules mentioned previously and keep your piles small — just 3 or 4 feet square, made of very dry wood stacked in layers set at 90-degree angles to each other, no more than 3 feet high. Keep it small and douse the wood when it's reduced to red coals.

2. DIG THE PIT

The burn pit should be conical, with the point facing downward. Dig the fire pit so it's about 3 feet in diameter, with sides that slope toward the deepest point in the center, about 3 feet deep. Remember, you don't have to dig it all at once! Take a few days if you need to.

Lay a generous, sturdy tarp on the ground. Shovel out the pit soil and dump it onto the tarp. Remove any large rocks from the excavated soil, and, while the tarp is still light enough that two people can move it, transfer the dirt to a place away from the fire pit. (You can consider using the soil as the basis for a new raised bed in your garden.) Then bring the tarp back for the next load.

Alternatively, you can do what Hawaiian biochar makers do and use the excavated soil to build up walls around the lip of

the pit. After the burn, shovel the soil back onto the biochar in the pit. Add some compost and mix it all together. The end result is a circular area of soil and biochar mix ready for planting. This allows you to conduct several burns exactly where the biochar is needed by simply rotating burn pits around the garden area.

ABOVE: *Building up walls of dirt around the pit allows you to then easily convert the pit into a biochar-rich growing area.*

3. LOAD YOUR FEEDSTOCK

Put your main load of feedstock, which will become the bulk of the biochar you produce, into the bottom of the pit. Do not

stack it tightly, as this will slow down the burn too much. Rather, tumble it in loosely or stack it in layers — one layer in one direction, the next layer above it perpendicular to the previous layer, and so on — until the pile is about 8 inches below the rim of the pit. Top the feedstock layer with a 1-foot-thick layer of very small, very dry, and densely packed kindling.

a

b

C

ABOVE: *Layer the feedstock by type in the burn pit with the heaviest wood (a, b) at the bottom and lightest (c, d) at the top.*

4. LIGHT THE FIRE

Light the top layer of kindling with a match or a propane torch. The torch is easier and lights the entire kindling layer quickly and evenly across its surface. As the kindling catches fire, it will draw air from the feedstock in the pit below it.

As the feedstock layer's top pieces start to burn, they'll produce smoke, but the kindling fire on top should consume

most of the smoke so that you don't see it, thus keeping the carbon within its charred remains instead of sending it into the atmosphere.

5. KEEP IT ROASTING

As the kindling is consumed, add more kindling on top. This will keep air moving up through the feedstock layer, providing fire that consumes the smoke, and encouraging the feedstock layer below to catch fire. The process will proceed fairly slowly

at first, but shortly, the entire contents of the pit will be blazing. The flame will be mostly yellow as the gases are consumed, and very little if any smoke will be produced. That's what you're aiming for here, as the setup is constructed to burn off the gases. If the kindling burns off before the feedstock turns into biochar, then add more kindling. The purpose of the kindling is to keep a good fire going on top of the feedstock to combust the smoke and volatiles coming off the feedstock.

As the fire in the pit slows down over the next 45 minutes to an hour, use the steel-tined rake to push unburned remnants in toward the center of the pit. Soon the feedstock in the pit will have collapsed into a thick bed of red-hot coals. It's at this point, before the feedstock burns to ash, that you want to stop the fire.

ABOVE: *Add more kindling as the top layer burns down to keep air moving up through the feedstock layers.*

6. DOUSE THE BURN PILE

This is a critical point in the process. You want to douse the fire while the feedstock is red coal but before it turns to white ash. It's better to douse too early than too late. You can always burn the feedstock a little more later, but once the feedstock is ashes, it's gone.

With the hose, thoroughly wet the red coal bed. Rake the wet coals to reveal any hot spots and spray with more water until you're sure that the coals are no longer smoldering and are entirely cold.

ABOVE: *Douse the pile to kill the burn before the organic matter goes to ash.*

ABOVE: *When finished, biochar should be black, cold, dry, light, and rigid but easily crushed.*

7. LET IT DRY OUT

After you've made sure the coals are out, let them sit for a day then check to make sure the fire hasn't started up again. Then

rake the coals again, douse with more water, and allow them to sit for another day. At this point, when you pick up the coals in your hands, they should be black and cold to the touch. The biochar should crumble easily in your hands. Wet biochar can go straight into the compost pile or other system for activation, such as a container of worm castings, as long as you're sure it's fully extinguished and not smoldering.

If you have any white ash, it means you let the fire burn the feedstock too far. Next time, get the water on the coals as soon as the feedstock collapses into red-hot coals.

When Is It Done?

Properly made biochar is light and rigid but easily crushed. It's fine-grained and not resistant to being ground to powder. It feels dry, not greasy. It rinses off your hands easily with water alone. And if you drop a piece onto a hard surface, it should make a slightly metallic ringing sound.

making biochar in a TLUD **COOKER**

In addition to the open pit method, there are two other ways to make biochar that are ideally suited for the home organic

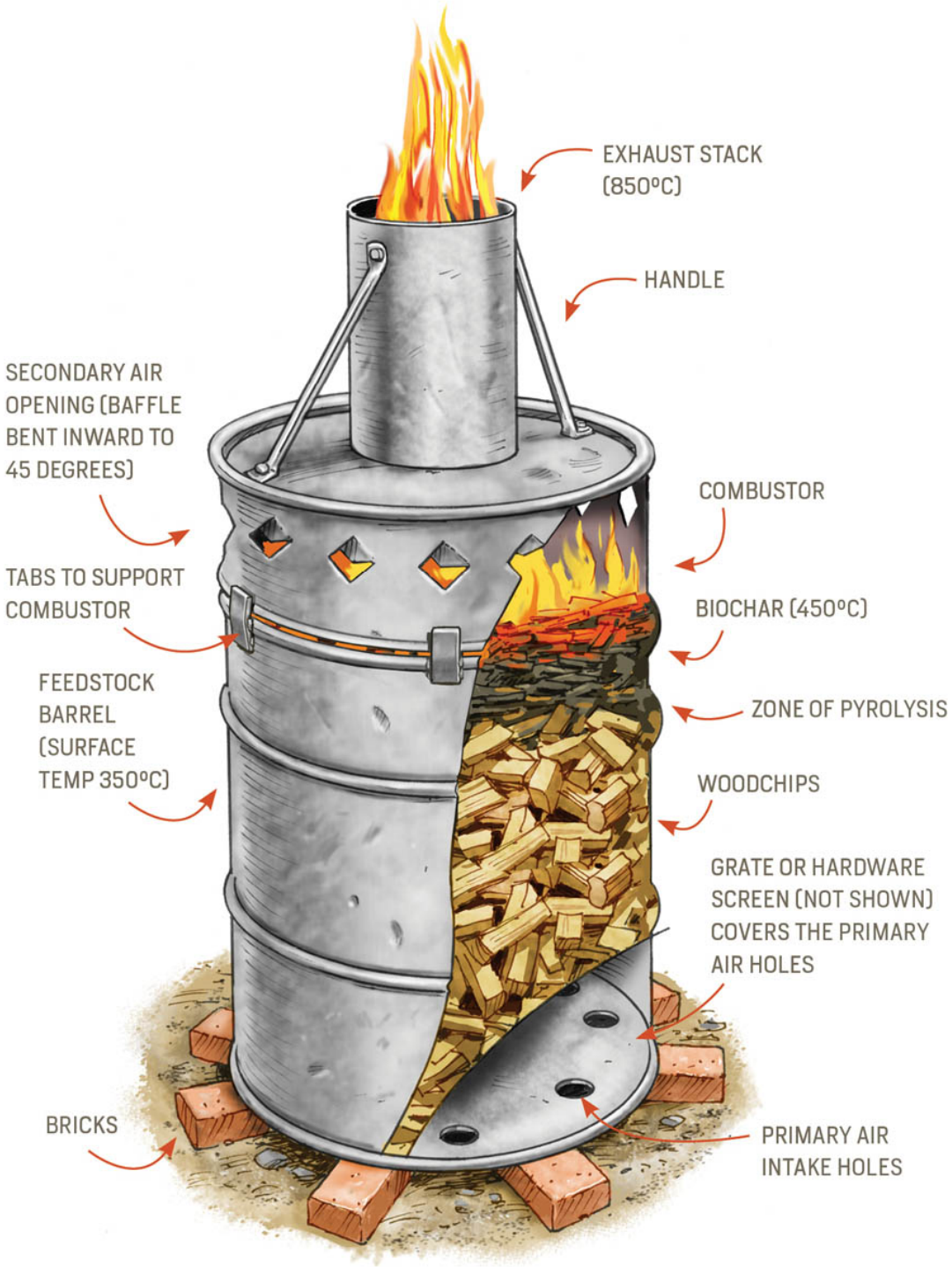
gardener: (1) the ammunition can and (2) the TLUD (Top Lit Up-Draft) gasifier. Both produce less ash and have about a 30 percent yield of biochar from the raw feedstock versus about 20 percent for most other forms of making biochar. Both are inexpensive, very safe to use, have clean emissions, operate at the proper temperature, are environmentally sensitive, and make a high-quality biochar for garden soils.

TOP LIT UP-DRAFT GASIFIER

One efficient method of making biochar is to convert two 55-gallon steel barrels into a TLUD and use a third as a quenching barrel. The advantage of a TLUD is that it produces very little carbon monoxide and extremely low particulate matter. It is the "cleanest biochar kiln on the planet," according to Norm Baker, who shared his design with us (see here).

Both Norm Baker and Paul Taylor, author and editor of *The Biochar Revolution,* have been instrumental in helping develop this TLUD biochar kiln. The TLUD will produce about 16 to 17 gallons of biochar — enough biochar to amend about 102 square feet of soil to a 5 percent volume level.

TLUD: TOP LIT UP-DRAFT GASIFIER



OPERATING PRINCIPLES

- Fill with dry, woody feedstock. Do not use green or wet wood.
- Light the fire on top with charcoal starter and a propane torch.
- Woody feedstock is gasified in the zone of pyrolysis and creates biochar.
- Secondary air burns the smoke and the volatile gases coming off the wood.
- Pyrolysis starts at the top of the feedstock and progresses down. Biochar will fill about $^{1}/_{3}$ of the barrel when done.
- Careful tuning and design produces almost no smoke and very little atmospheric pollution.

HOW TO BUILD A TLUD

You will need two 55-gallon barrels to construct the TLUD. Both should be clean “open top” barrels and be from the same manufacturer. Otherwise, small dimensional differences between manufacturers will cause the parts to fit imperfectly and make construction difficult. You will also need common metal-cutting tools: an angle grinder, drills and bits, files, a jigsaw, and a reciprocating saw. Especially useful is a 4-inch angle grinder with silicon-carbide metal-cutting wheels. The

cutting wheels come in three different thicknesses. The 1.6-mm-thick wheel is the most useful for building a TLUD.

It is critically important to wear eye and hearing protection when working with metal to build TLUDs. If you can't — or don't want to — do this work yourself, a metal fabrication and welding shop will probably take on the task.

METAL-CUTTING TOOLS

ABOVE: *4" angle grinder*

ABOVE: *drill and bits*

ABOVE: *reciprocating saw*

ABOVE: *jigsaw*

Step 1: Create the feedstock barrel

One barrel is the feedstock barrel. Drill 10 holes in the bottom to feed primary air into the pyrolysis zone. The holes are 11/16-inch in diameter and are easily drilled with a stepped drill bit.

See the diagram on here for an illustration of the primary air intake holes.

Include a grate or sheet of hardware cloth (wire screening with 1/4-inch mesh) inside the barrel to keep the woodchips from covering the primary air intake holes.

ABOVE: *Place a grate, like this one, or a hardware screen in the bottom of the feedstock barrel.*

Step 2: Create the combustor

Cut the second barrel completely around with the angle grinder 5 7/8 inches from the bottom of the barrel. This piece

will be the combustor portion of the TLUD. Flip the piece over so that the bottom of the barrel is now the top surface. Cut 16 diamond-shaped holes into the sides. Make initial cuts with the silicon-carbide wheel. For safety's sake, finish and trim the initial cuts with a metal cutting blade inserted into a jigsaw. For each diamond-shaped hole, only cut three sides. Bend the fourth (upper side) of the diamond shape inward toward the center of the combustor at a 45-degree angle to form a baffle. These diamond-shaped holes are the source of the secondary air that burns the gases coming off the wood.

Step 3: Add support tabs for stability

The feedstock barrel must support the combustion chamber, and usually this is done with tabs. Use an angle grinder and cutting wheel to cut ¾-inch deep slits 1 inch apart around the entire lower edge of the combuster to create bendable tabs. Using a pair of pliers, bend two or three of the tabs outward at a 45-degree angle. All of the remaining tabs should be bent inward at a 45-degree angle so that the combustor fits slightly down into the open top of the feedstock barrel. The tabs can also be welded on (as shown).

ABOVE: *The support tabs on my own TLUD are welded onto the feedstock barrel.*

Step 4: Construct the stack

An air duct 12 inches in diameter and 24 inches long (available at building supply stores) makes for an excellent stack. The stack can be centered on top of the combustor or offset to one side of the combustor if you want to create a cooking surface while making biochar. (Since a typical burn requires about 1 hour and 20 minutes, there is sufficient time to cook a meal on

top of the TLUD. The surface temperature will reach about 350ºC, but you can put a grate under your cookpot to cook at a lower temperature.)

Place the air duct on top of the combustor where you want it. Reach into the duct with a pencil or marker and trace a circle onto the top of the combustor. Use a jigsaw or reciprocating saw to cut the circle out of the top of the combustor. It may be necessary to drill a couple of ¼-inch holes along the inside edge of the circle to have a place to insert the saw blade.

ABOVE: *Set the stack to one side if you want to make a cooking surface.*

Use tin snips to cut tabs 1-inch wide and ½-inch high along the bottom edge of the air duct. Using pliers, bend them outward to 90 degrees. Center the air duct tubing over the hole in the top of the combustor. Choose several tabs as attachment points to the combustor. Steel POP rivets work well to attach the stack to the combustor. Aluminum POP rivets will disintegrate and melt from the heat of the TLUD. Self-drilling (also called self-tapping) sheet metal screws also work well.

Finally, you can attach handles to the combustor for easy positioning and removal on the feedstock barrel. Electrical conduit, ½ inch in diameter, cut to 20 inches long works well. Flatten 1½ inches of the ends by crushing in a vice. Finish flattening the ends with a hammer. Bend the ends to accommodate the angles on the stack and combustor. Attach the handles with ¼ inch nuts and bolts.

Step 5: Create the quenching barrel

You'll need one more barrel to use as a quenching barrel after the biochar has been made. Drill a ¼-inch hole into the bottom for drainage.

ABOVE: *The finished TLUD has three parts: feedstock barrel, combustor, and stack.*

HOW TO OPERATE A TLUD

Step 1: Set up the feedstock barrel

Set the feedstock barrel on a few bricks to allow airflow underneath. Completely fill the feedstock barrel with dry wood chips, wood shavings, landscape trimmings (packed as densely as possible), or any dry, woody feedstock. Just remember, the feedstock should ideally be no more than 1½ inches in its widest or thickest dimension. Thicker feedstock will not pyrolyze fully and will have to be separated from the rest of the biochar at the end of the burn and placed on top of the feedstock for the next burn to complete pyrolysis.

Step 2: Light the feedstock

Light the wood shavings with a charcoal lighter or propane torch. Immediately place the combustor on top of the feedstock barrel. The flames in the combustor will be a yellowish-orange

color. There will be some smoke at the start as the metal in the combustor increases in temperature. Once pyrolysis is going full speed, the production of smoke will cease, and you will see and hear turbulent flames inside the combustor through the diamond-shaped holes.

ABOVE: *Feedstock should be small, light, and tightly packed into the cooker.*

Step 3: Monitor the burn

As pyrolysis proceeds, the pyrolyzing action migrates about two-thirds of the way down inside the barrel. The roaring sound slowly stops and the yellow flames begin to decrease in height. They will be visible through the diamond-shaped holes in the combustor. The biochar will be glowing a bright, beautiful, red-orange color. Eventually the flames will self-extinguish, and there may or may not be another puff of smoke. The full burn will take 70 to 90 minutes, depending on your feedstock.

ABOVE: *A handheld infrared temperature sensor is an easy way to test the surface temperature of the feedstock barrel.*

Step 4: Remove the combustor and quench the biochar

Once the flames have extinguished, put on welding gloves and remove the combustor, setting it aside on the ground. When you see a tiny amount of grayish white ash forming on the edges of the biochar, immediately pick up the feedstock barrel (again, using welding gloves) and dump the biochar into the quenching barrel. If the biochar is not quenched, it will continue burning and eventually burn completely to white ash.

Set the hot feedstock barrel aside. Immediately soak the biochar with water from a garden hose. Stand on the upwind side when you quench the biochar because enormous amounts of steam will billow up. Completely flood all of the biochar. The quench barrel can be left in place on the ground to drain the excess water away.

ABOVE: *The quenching barrel prevents the biochar from cooking more than it should.*

When cold, the biochar is now ready to be crushed and inoculated with manure tea or worm castings, or worked into the compost pile and later used in your garden. It does not have to be air-dried.

Almost everyone who makes enough biochar will have had the experience of not quenching one hot spark somewhere deep inside the quench barrel, only to return later and find all of the biochar fully combusted to ash. Sometimes adding a new batch of biochar containing just one glowing spark to a barrel used to store previous batches will result in the entire barrel combusting to ash overnight. So be warned and be careful to thoroughly quench your biochar.

Lastly, protect your TLUD from wet weather. Otherwise, it will completely rust away in a few years.

ABOVE: *Finished biochar is ready to be crushed and inoculated.*

making biochar in a **METAL CAN**

If you have a wood-burning stove in your house or outbuilding, you can make biochar in a metal can with a lid. (An ammunition can from a military surplus store or hunting retailer works well.)

The can should be small enough to fit into the wood-stove. Using a screwdriver, remove any rubber gasket from inside the lid and fill the can with woody waste. After the woodstove burns a load of firewood down to hot, glowing coals, lay the can directly on the hot coals. As the can heats up, you will see wood gases escaping and catching fire around the lid of the can. The beauty of this method is that biochar is made while you're simultaneously heating your home.

Eventually, when the coals go out and the stove cools, open the stove and remove the can to retrieve the biochar.

You can also pyrolyze animal bones in the can to make bone biochar. This is a great way to recycle bones and add calcium or phosphorous to your garden soil. The biochar you make in the can will be dry and should be wet down and inoculated before use.

ABOVE: *You can pyrolyze small pieces of wood, as well as household compost materials, in a metal can in a woodstove.*

a yearly schedule for
MAKING BIOCHAR

I recommend accumulating woody landscape debris throughout spring and summer, letting it dry completely, and making biochar in the fall.

Many people prefer to chip landscape debris as it accumulates. Woodchips stored in feedstock barrels dry over

the summer when you let the barrel stand in the sun. Cover the top loosely to keep out rain, and raise the barrel up on three bricks to allow air circulation underneath. The chips will be dry by fall. Chipped woody debris makes more biochar at each burn because the chips can be packed more densely in the barrel than branches.

On a larger scale, you can construct four or more TLUDs and burn them in quick succession to make large amounts of biochar in a single day. Start each one burning about 30 minutes apart and there will be sufficient time to take care of all the tasks required for each TLUD. A total of 13 burns will produce 1 cubic yard of biochar — enough to amend approximately 1,300 square feet of soil to a 5 percent volume of biochar. Building four TLUDs with new materials will cost about the same as buying a cubic yard of biochar, but TLUDs can be used for 60 to 100 burns before they disintegrate.

after cooking:

RAKE, BAG, AND CRUSH

After the biochar is fully cooked, it needs to be crushed. Finely ground biochar has a much greater surface area than larger chunks, and it's the surface area that facilitates the transport of electrons through the soil, supporting the biological functions of soil life. Fine biochar particles do an excellent job

of loosening dense soils and making loose soils more cohesive. How finely should you crush it? The smaller the better. Pieces smaller than ¼ inch are good, but pieces the size of sesame seeds are better, and powder is best.

To crush the char, rake it up, put it into sturdy burlap or canvas bags, and drive a vehicle back and forth over them. Shake the bags and flip them after every few passes of the vehicle. Alternatively, if you have a cattle or horse barn, goat pen, or chicken pen, you can put the biochar in there and the animals will not only crush it and peck it to pieces, they'll inoculate it with their manure and urine.

ABOVE: *Roasted biochar must be crushed as fine as possible.*

buying BIOCHAR

If you don't want to make biochar at home, you can purchase it at a garden center, in a stock-and-feed outlet, or from online retailers. You'll find a list of resources. When buying biochar, you might wonder: Is all biochar the same? Is some better than others? How and why does it differ in quality, and how can I be sure I'm getting the most bang for my buck? Good questions!

MINERAL VALUE OF MAPLE CHIP BIOCHAR

While the main functions and purposes of biochar are to sequester carbon, improve soil, and support the soil ecosystem, it also has some value as a supplier of minerals. These minerals are part of the microbial food supply. The following table gives you an idea of the mineral content of maple chip biochar.

Mineral	Mg per Kg of Biochar	As a % of the Biochar
Sulfur	403.1	13.7
Magnesium	197.0	6.7

Calcium	174.6	6.0
Phosphorus	94.9	3.2
Potassium	85.7	2.9

ABOVE: *Premium grade*

ABOVE: *Mid-grade*

ABOVE: *Regular grade*

ABOVE: *Commercially available premium grade biochar is used for hydroponic gardening. Mid-grade is good for potting soils. Regular grade can be used for field application.*

CHOOSE WHAT'S RIGHT FOR YOUR GARDEN

Biochar isn't a homogenous product: it varies in texture and composition based on the feedstock used to make it. Different species of plants or types of organic matter will make biochar with varying characteristics. And feedstock can vary depending on the climate and soil type the plant was grown in,

how much water it had access to, and other regional factors. Biochar will also vary depending on the production method used. Differences in pyrolysis temperatures, the amount of water in the feedstock, how much air gets to the roasting feedstock, or the length of processing time can all contribute to variations in the final product. In general, a fine, powdery product has the most surface area and is preferable to chunky biochar for gardening purposes. And properly finished biochar powder should feel dry, not greasy, and should be easily rinsed from your hands with just water.

Which product is right for you? Other than particle size, you can't tell much about the product by simply looking at it. Yes, the smallest particle sizes are best for the garden, but also check the manufacturer's website for information about feedstocks used. Hardwoods are good, softwoods may be better, and farm wastes like straw may be best. Animal-derived organic matter like manure and poultry waste are less desirable because manure does not have the pore structure that makes plant feedstock biochar such a good habitat for microbes.

Biochar is often classified by grades: premium grade, mid-grade, or regular grade, based on its particle size and carbon storage potential. Premium grade — with the smallest particle size — is used as a substrate for the hydroponic growth of tomatoes, cucumbers, and bell peppers in greenhouses. Premium grade is also used to decontaminate soil and water, and to remove excess phosphate from ponds and lakes experiencing algae blooms. After these uses, premium grade biochar can be turned into the soil. Mid-grade biochar, mixed with compost, is great for making potting soils for starting

vegetable and flower seedlings. Regular grade biochar, also mixed with compost, is used for field application and land reclamation.

NOTES FROM THE FIELD

BIOCHAR AND THE BAKERS

Norm and Peggy Baker are pros at making biochar at home. The Bakers are lifelong growers and gardeners of everything from orchids to vegetables. Norm grew up on a farm where he learned to love plants. After a career in academia with advanced degrees in entomology and ecology, he and his wife, Peggy, started Northstar Nurseries, a specialty nursery for daylilies in Minnesota.

As new nursery owners, the Bakers began attending professional meetings to learn about running a horticultural business. In a workshop on soil fertility taught by a University of Minnesota professor, someone asked the question, "What is the most fertile soil in the world?" The professor replied, "There is a soil in South America called terra preta that is incredibly fertile, but we don't know what makes it work." It struck Norm that this investigation should be a high priority topic in scientific research.

Years later, when the Bakers retired to Sequim, Washington, on the Olympic Peninsula, they encountered the use of biochar. They were initially skeptical of the so-called miracle soil. Sounds too good to be true, they thought. But with Norm's research background, they started designing experiments to test biochar and its "too

good to be true" applications. The promise of biochar — made from wood that would normally be wasted — might work really well in organic gardens, they thought. They also began attending regional meetings on biochar and classes on Top Lit Up-Draft gasifiers taught by Art Donnelly of SeaChar (a nonprofit organization focused on developing strategies for "carbon-negative living"). This led to several years of tinkering with TLUD designs, some garden experiments with biochar, and a biochar urinal. These efforts were often collaborations with other biochar enthusiasts, and the results of these experiments exceeded expectations. The Bakers say they have been amazed at what people can accomplish when they apply hands-on work to something they believe to be truly worthwhile.

Today, the Bakers give frequent presentations and talks to environmental, gardening, horticultural, and humanitarian organizations about the benefits of biochar. They have greatly improved sustainability on their own property. Quick-and-dirty calculations show that the Bakers' organic garden of 2,400 square feet has sequestered nearly 3,000 pounds of CO_2 directly from the atmosphere. What was once an abundance of landscape waste on their small hobby farm is now a sustainable source of wood to heat their home and create significant quantities of biochar. On top of that, the quality and yield of their vegetables are phenomenal. Because of their personal experience with biochar, the Bakers feel strongly that it

will play a large role in helping to create a more environmentally sustainable future.

ABOVE: *Norm and Peggy Baker are biochar trailblazers.*

CHAPTER 3

inoculate your **BIOCHAR**

WIDE MOUTH

All plain biochar needs to be inoculated to express its benefits in the garden. Adding raw biochar to garden soil can actually retard plant growth, not enhance it, because the substance repels water and contains no microbial life. When you inoculate biochar, you load it with microbial life, ready to help enrich your soil. In addition to enlivening biochar, it's also important to moisten it, to make it capable of locking moisture away in the soil.

WHY
inoculate it?

Think of biochar (especially when made from wood) as an enabler and preserver of soil health rather than a supplier of nutrients. When you inoculate it, you are seeding your biochar with thousands of species of microorganisms — trillions in every shovelful. These soilborne microorganisms are the foundation of all life on earth. They act independently to some extent but are much more powerful when they form ecological alliances and colonies. Working together, the microbes dismantle decaying plant matter and release nutrients in soluble form to produce **humus** — fully decomposed organic matter, high in nutrients, rich in minerals, and vital for healthy plant growth. When biochar is present, the natural decomposition process is strengthened and made more potent because humus and biochar are both reservoirs that hold these

liquefied plant foods on their surfaces, so they don't wash away in rain or irrigation water.

Mixing uninoculated biochar into garden soil, the way you'd mix in compost, is not ideal. Plain biochar doesn't provide nutrients and may even set back some garden plants. It may not increase plant growth or soil health, and some studies have shown that using uninoculated biochar could actually cause a decrease in plant growth for the first year or two.

Inoculating your biochar will:

- Balance the pH of the soil, tending toward pH 6.5, which is slightly acid. This is the pH at which nutrients are most bioavailable to many plants.
- Increase the cation exchange capacity (CEC) of the soil.
- Allow for synergies and symbiotic relationships to arise when the soil becomes a robust and balanced ecosystem.

ways to inoculate **BIOCHAR**

There are a number of ways to inoculate your biochar. You can use one of the methods below, or you can combine any of them together. Which method you choose is not the most important factor; they all work. Choose the one that's most convenient for you. What's important is the end result: that your biochar is loaded with microbial life and ready to become an effective soil amendment.

CO-COMPOSTING

One of the simplest and best ways to inoculate biochar is to co-compost it with the materials you'd normally build your

compost pile from. It's preferable to use your own homemade compost, simply because you can control the inputs. The more diverse the source material for your compost is, the more microbially diverse your inoculated biochar will be.

1. Make your pile by layering high-carbon materials (dried leaves, straw, plant wastes) and high-nitrogen material like chicken manure, fresh grass clippings, and farm animal manure. Most sources agree that a 30:1 ratio of carbon to nitrogen is ideal, but in my experience over the years, I've found that there is flexibility here. In my own compost heap, a ratio of just 4:1 has worked well.
2. Mix the biochar into your compostable materials in a ratio of two parts biochar to five parts compost by volume (about 40 percent biochar to 60 percent compost), adding the biochar as you make the layers.
3. Keep the mixture moist (but not sopping wet) by watering it; it should feel like a squeezed-out sponge.
4. Turn it with a pitchfork or shovel every week or two (stir the pile like you would with regular compost).
5. After the compost pile heat subsides and it is finished, let it sit for four to eight weeks so that the biochar can become fully charged.

The Importance of Adding Water

Straight from the burner, most biochar is hydrophobic, meaning that it repels water. The heat of the fire has driven off any water molecules, and the oils and resins in the wood have been liquefied and cooled, forming shiny, slick surfaces that water can't immediately penetrate. In addition, raw biochar is often sold as a powder — a light and fluffy powder that is hard to use, should not be inhaled, and will blow away in even a light breeze. However, by mixing a minimal amount of water with the raw char — just enough so that the charcoal holds together but can still be easily handled and worked and is not waterlogged into a gooey mass — microorganisms will soon get to work digesting those oils and resins. Within a week or two of being moistened and mixed with a biologically active material like compost, the char will become hydrophilic, which means it will soak up and hold water.

MIX WITH MANURE

Rather than co-composting your biochar to inoculate it, you could mix it with a slurry of farm animal manure (but never domestic animal manures, as these can carry human pathogens). Here are my choices for the best manures for adding microbes and minerals to the garden or the biochar:

- Pig manure
- Goat manure
- Chicken or turkey manure

- Rabbit manure
- Bovine and sheep manure
- Horse manure

Cow, cattle, sheep, and horse manure are okay, but they have less nitrogen, and these animals tend to eat weeds with ripe seeds, which will spread weeds in your garden.

MIX WITH WORM CASTINGS

Mixing biochar 50-50 by volume with worm castings is an excellent way to inoculate it. Worm castings are the residue of organic matter that's been through the digestive system of a worm — in other words, worm poop. Worm castings are seven times richer in major plant nutrients than compost is. You can buy bags of dried worm castings, or you can generate your own by keeping a worm bin (see here).

For every 10 gallons of this 50-50 mix of biochar and worm castings, add a cup or two of flour and enough water to make a wet slop — not so little as to make a paste, and not so much as to make a slurry. The flour becomes food for fungus that will colonize the mix with hyphae — those long, threadlike filaments that fungi use to cruise through and connect with the soil. Encouraging fungi in your biochar activation regime will result in better soil particle aggregation; that is, it will be more crumbly and friable, with larger particles and better water-holding capacity.

The flour helps bring the mixture to life. It will ferment rapidly and be usable in about three weeks, although it can go much longer if you wish. Just make sure the mixture is moist and is kept covered from rain and direct sunlight. In addition to, or along with, the flour, you can add a little molasses dissolved in water, or substitute cornmeal for the flour. These sugars and starches help the mixture heat up and ferment quickly.

Keep in mind that none of these proportions of biochar to activation materials is set in stone. These are biological systems we're dealing with, and a little experimentation is always good.

It may be usable in three weeks, but it's preferable to let the mixture sit for four to eight weeks to become fully colonized by microbes and so that they will have had enough time to get their miniscule ecologies going.

Worms Eat My Biochar

To ensure a nonstop supply of worm castings to mix with your biochar, your best bet is to raise your own worms. Red wigglers (*Eisenia fetida*) are the best species for home worm bins, and they can be purchased from online suppliers. I have three round, plastic worm bins, each with four trays, and I harvest a good cubic yard of high-nutrient castings from them each year.

The worms will transform your kitchen vegetable scraps, trimmings, and leftovers into a dark, crumbly soil within weeks. The red wigglers like all vegetable matter except hot peppers, citrus rinds, and trimmings from *Allium* species (onions, leeks, shallots, garlic, chives). Avoid feeding them any animal products (meat, eggs, cheese), although eggshells add calcium to the castings and the worms seem to like curling up in them.

I use a worm bin called Can-O-Worms. On the bottom is a round pedestal on three legs with a drainage faucet for liquid drippings that plants love. I set a deep-sided pan under the faucet to catch the drippings. You may like a cocktail before dinner, but your plants will love this "worm juice," as I call it — a rich, dark liquid produced by thousands of red wigglers chewing their way through your kitchen scraps. A round tray with hundreds of small holes in the bottom is set on the pedestal, and bedding made of strips of wet newspaper is placed in the tray. The worms are placed on the newspaper and given their first bucket of kitchen scraps. Then a cover is set on top.

Over time, this tray will fill with scraps and partially digested castings. Then a second tray is placed atop the first one, given a bucket of scraps, and the top set back on. As the worms in the lower tray finish eating the material in that tray, they migrate upward into the new tray through those holes. Then the process is repeated until all four trays and the lid sit atop the pedestal. At this point, it's time to harvest worm castings.

I remove the top tray with relatively fresh scraps in it and set it aside. Then I turn the lower three trays over onto a tarp. The worms don't like sunlight, so they hunker down in the castings. Using my hands (with kitchen gloves), I scrape the top layer of castings from the mound and transfer it to a container. This exposes worms, which again retreat away from the light. After they retreat, I scrape more castings and put them into the container. I repeat the process — it may take a few sessions over a few days, but no large amount of time — until I have a large mass of worms left. Some few worms may have made it with the castings into the container, but that's okay.

Now I hose off the pedestal and empty trays, making sure that the faucet on the pedestal isn't clogged, and place the tray I set aside with the fresh scraps back on the pedestal. I transfer the mass of worms onto this tray and put on the top, and I'm ready for the next cycle. I find that I have to repeat this work every six months or so, but those worm castings are black gold, so I don't mind.

PUT YOUR CHICKENS TO WORK!

If you keep chickens, you might have learned that by tossing your kitchen scraps into their pen along with fallen leaves in autumn, the chickens will scratch the scraps and leaves into tiny pieces and mix them with their droppings. This makes a highly nutritious plant fertilizer. And it makes a wonderful partner for biochar. Simply spread a ½-inch to 1-inch layer of biochar on the pen floor. The biochar will deodorize the vegetable-and-chicken-poop mixture (bonus for you!), and the hens will do work of inoculating the biochar. After three or four weeks, rake up the scratchings and biochar mixture and make a pile out of it, moistening it with the hose as you pile it up. Cover it and see if it heats up. Chicken manure is rich in nitrogen — so rich it can burn young plants if it hasn't composted and rotted enough. When it is just warm-to-the-

touch, the manure is stabilized at a safe level. If it does heat up to 120ºF or above — it will feel hot if you put your hand into it — wait until the heat subsides before using it in the garden. This biochar will be fully inoculated!

Feed Your Animals a Little Biochar

We know that biochar needs to be inoculated with microbe-rich materials for it to become optimally functional in the garden. And what place is more microbe-rich than the intestines of animals? There are billions of biochar-activating microbes in animal digestive systems. So mixing a little finely powdered biochar into the food of farm animals is a logical idea, as the biochar will be inoculated during its passage through the alimentary canals of our farm friends.

Make note: This method of activating biochar and improving the grow-power of farm animal manures applies only to plant-eating animal species, or omnivores like pigs that are fed a plant-based diet. Do not compost the manure of meat-eating predator species — including pet dogs and cats — because they could harbor parasites and disease organisms that affect humans.

SOAK IN NUTRIENT-RICH LIQUIDS

Inoculating biochar can also be as simple as soaking it in nutrient-rich solutions such as fish emulsion, urine, or fermented seaweed, compost tea, manure, or “worm juice” from your worm bins. Mix the biochar 50-50 with compost tea or other nutrient-rich liquid and let it sit for a month. Stir it up every few days and don’t let it dry out.

ABOVE: *Mixing biochar with compost tea suffuses it with nutrients.*

MIX WITH FINISHED COMPOST

One of the simplest and most effective ways to inoculate biochar is to mix it with finished compost in a ratio of two parts compost to one part biochar by volume. Do this in a leak-proof container, such as a 5-gallon plastic bucket. Fill the bucket halfway with the compost-biochar mixture and fill the rest of the bucket with water. Stir it up well and stir it again every few days for about a month. At the end of that time, drain off the liquid into a separate bucket and use it to water or foliar-feed plants. Use the heavy, wet compost-biochar mixture on garden soil, to top dress plants, or around planting holes. It will be thoroughly inoculated.

ABOVE: *Mix two parts finished compost with one part biochar by volume to inoculate biochar.*

give it a mineral **BOOST**

Many soils are deficient in certain minerals that plants need for adequate growth, including phosphorus and potassium, and some trace elements like magnesium, manganese, zinc, and calcium. Adding these into your biochar during the activation process is a good idea. It doesn't matter when you add them — just throw in a handful or two. Extra phosphorus can be supplied by ground rock phosphate. You can add potassium with a soil amendment called greensand. Trace elements can be supplied by seaweed extracts, fish emulsions, or commercial products that are formulated to be rich in trace elements.

Another way to boost the plant nutrients in biochar is to mix in 1 tablespoon of micronized rock powder. This is finely ground volcanic rock, often sold under various trade names like Azomite. If you work with these materials, wear a mask to avoid inhaling them. Rock powders contain 50 or more trace elements found in magma that flows to the surface of the earth during volcanic eruptions. You can also add a handful of flour (or rice bran) to the biochar-rock powder mix to provide food for microbes, and two handfuls of worm castings to create a rich mix of living soil microorganisms. Toss this all together, moisten it, cover, and allow it to ferment for two or more weeks.

ABOVE: *Mixing micronized rock powder into biochar adds trace nutrients.*

CHAPTER 4

using biochar
IN THE GARDEN

Now that your biochar is colonized with soil-enriching microbes, you can mix it into the soil in your garden beds, or mix it with more compost and then fertilize your beds with that. Biochar won't burn plants like high-nitrogen materials will, and because of the fermentation, the nitrogen will have been subsumed into the bodies of the microbes. These little guys don't live very long, and when they die, their cell contents spill liquid fertilizer into the soil solution, where it feeds plants directly — and indirectly by dissolving minerals out of rock particles.

You can use biochar liberally or sparingly, depending on what you're growing and the kind of yields you expect. In the vegetable garden, light feeders — that is, crops that don't require a large charge of nitrogen such as carrots, garlic, leeks, onions, parsnips, potatoes, rutabagas, shallots, and turnips — need only 1 inch of inoculated biochar dug into the top 4 to 12 inches of soil; while heavy feeders like tomatoes, beets, cabbage family crops, green leafy vegetables, cucumbers, melons, squashes, and peppers take a 4-inch layer dug into the soil.

ABOVE: *Using biochar in the garden decreases the need for nitrogen fertilizers.*

know
YOUR pH

When you're gardening, it's important to know the pH of your soil — essentially, how acid or alkaline it is. Certain plants are better able to take up nutrients in acid soils, while other plants need an alkaline soil to thrive. The pH (hydrogen potential) scale runs from 0 to 14.0, with a pH of 7.0 as neutral. Nutrients are most bioavailable to *most* plants at a soil pH of about 6.5 —

slightly acid. As a soil becomes more acid (less than pH 7.0) or more alkaline (above pH 7.0), some plant nutrients become less and less bioavailable, and the soil becomes limiting in one nutrient or another.

Adding biochar to your soil will raise the pH slightly, so the gardener must use biochar in appropriate amounts. More is not necessarily better, especially in soils rich in humus and organic matter that are already in the 6.5 pH range. Using biochar too liberally could raise the pH into the alkaline range, which could slow the growth of acid-loving plants such as blueberries and strawberries. How much is too much? To avoid pushing the pH into the alkaline range, use the ratio of 1 to 4 pounds of biochar spread over 10 square feet — that is about 1 to 4 inches of inoculated biochar sitting on the surface — depending on whether your crops are light or heavy feeders. The light feeders take 1 inch; the heavy feeders take 4 inches.

A SIMPLE SOIL TEST

You can test the pH of your soil while also getting a sense of the amount of organic matter at the same time. Shake a cup of soil in a quart jar of water, then assess how the soil elements fall out. On the bottom will be stones and sand; above that, you'll see silt, and above that is clay. Organic matter will be a dark band at the top (if there is any organic matter in your base soil).

Use pH strips to test your soil pH. A soil pH of 6.0 to 6.5 and a layer of organic matter equal to about 5 percent of the solids by weight is ideal for most gardens.

HOW TO ADJUST THE pH

Most garden soils have a pH between 5.5 and 8.0. A pH below 6.0 is too acid for most vegetables; if your soil is this acid, you'll need to add ground limestone. If the pH is above 7.5, the soil is too alkaline for most vegetables, and you need to add actively decaying organic matter, decaying pine needles, or elemental sulfur. Sulfur, a natural element, is allowed in organic gardening and farming.

Cooperative Extension Service offices, soil labs, and many lawn and garden centers have charts showing how much lime or sulfur to add to adjust soil pH. This information is usually given as pounds of amendments to add per 1,000 square feet, so you need to measure the size of your vegetable garden first. Then use those tables to figure out how much lime or sulfur you need to add to your soil. Most application rates will only raise or lower pH by one point per year (from 7.5 to 6.5, as an example).

POUNDS OF LIMESTONE NEEDED

TO RAISE PH FROM EXISTING PH TO TARGET (PH 6.5) PER 1,000 SQUARE FEET

pH	Number of Pounds for:		
	Sandy Soil	Loam Soil	Clay Soil
4.0–6.5	60	161	230
4.5–6.5	50	130	190

5.0–6.5	40	100	150
5.5–6.5	30	80	100
6.0–6.5	15	40	60

POUNDS OF ELEMENTAL SULFUR NEEDED

TO LOWER PH FROM EXISTING PH TO TARGET (PH 6.5) PER 1,000 SQUARE FEET

pH	Number of Pounds for:		
	Sandy Soil	Loam Soil	Clay Soil
8.5–6.5	45	60	70
8.0–6.5	30	35	45
7.5–6.5	10	20	25
7.0–6.5	2	4	7

(Source: National Gardening Association)

The best way to apply sulfur and limestone evenly to your soil is to use a lawn fertilizer spreader. You push it along, and as the wheels turn, they allow the soil amendments to fall

through a revolving tube with holes in it. Handheld spreaders also work well, or you can spread these materials by hand. Wear gloves and try to spread them as evenly as possible using a sweeping motion of the arm, allowing the amendments to flow evenly from your hand. No matter how you spread the materials, make sure that you work them into the soil and water it well afterward. Your soil uses limestone and sulfur most efficiently when they're tilled or turned into the soil to a depth of 4 to 6 inches.

If raising the pH is your goal, look for dolomitic limestone rather than calcitic limestone. It contains magnesium as well as calcium. Magnesium is as important as calcium for plant growth.

If lowering the pH is your goal, add sulfur. It usually comes in powdered form or is mixed with other nutrients, such as ammonium sulfate and magnesium sulfate. Sulfur is also called flowers of sulfur, soil sulfur, and powdered elemental sulfur.

improve your DRAINAGE

Biochar is a soil amendment, and it's best to improve your ground soil rather than simply put raised beds on top of poor soil. If you make raised beds on poor, compacted soil, water is likely to percolate through the topsoil and then run off laterally from the hard soil underneath, breaking down the

sides of your beds. Eventually that good topsoil will soften and improve drainage in the hard-packed soil below, but it may take a number of years to do this.

Good garden soil drains well, so that plant roots don't become waterlogged. You can test your soil by doing a perc test. The best way to improve drainage is to use a spading fork or tiller to break up the poor soil that's already there and shovel 8 to 10 inches of compost onto the broken-up soil, then dig the compost in so it mixes with the poor soil.

If you're using a tractor, attach a steel-tined soil ripper and rip the hardpan soil as deeply as possible. The tractor will drag the vertical tines of the ripper through the soil, breaking it into chunks and allowing air to penetrate and rainwater to infiltrate the soil. You can then reduce the size of the chunks by disc-harrowing the area, or by tilling it by hand.

ABOVE: *Biochar helps loosen compacted soil and improves soil aeration.*

using inoculated biochar to SPOT-FEED PLANTS

For dry fertilizer: Add 1 cup of inoculated biochar for each cubic foot of potting soil or garden vegetable bed soil. When transplanting seedlings into the garden, put 1 tablespoon of biochar in the planting hole, plant the seedling, and add

another tablespoon of the biochar to the soil surface of the filled-in planting hole. Alternatively, plant the seedling as usual, and add 2 tablespoons of inoculated biochar to the soil surface of the filled-in planting hole. Water it gently so as not to wash away the biochar.

As a liquid amendment: Add 1 cup of inoculated biochar to 5 gallons of water and stir it up once or twice a day for a week. Ladle 2 or 3 cups of this liquid directly onto the soil around your growing plants every two weeks. If you are watering your plants at that time with plain water, do your watering first and add the biochar liquid after the soil water has drained away. That way, the biochar liquid will penetrate the soil better than if the soil is dry, and you won't be washing it away with a regular deep watering with the hose or sprinkler.

ABOVE: *Biochar can be used as a liquid amendment.*

applying biochar to **GARDEN BEDS**

When you add biochar to a garden bed, it's a good idea to add organic matter at the same time, turn the soil, and water the

soil deeply. Turning the soil over to a depth of 12 inches loosens it and gets air down into the root zone. Adding compost is beneficial for any garden, but it's especially good if you have very sandy soil or soil with a lot of clay. If the soil is heavy clay, you can also add some coarse sand with the compost, to help lighten it.

Cover each garden bed with a liberal amount of compost and 1 to 4 inches of inoculated biochar per square foot. Using a shovel or spading fork, turn the compost and biochar into the top 12 inches of soil. You'll need about a gallon bucket of inoculated biochar to cover a 4 × 6-foot raised bed to a depth of 4 inches. You'd need about 2½ yards of biochar to cover eight such raised beds to 4 inches deep.

After adding the biochar mixture to the soil and turning it in, water the beds well and plant your seedlings or seeds. To give the microorganisms in the biochar a head start in establishing their complex ecosystem with the indigenous soil life, add the biochar mixture in the fall and plant in the spring.

Alternatively, if the beds are already planted, you can top-dress or side-dress individual garden plants with cupfuls of activated biochar (a 50-50 mix of biochar and compost). Cover the root zone with the mixture and dig it into just the top 2 inches of soil, so as not to disturb roots near the surface.

add biochar
OVER TIME

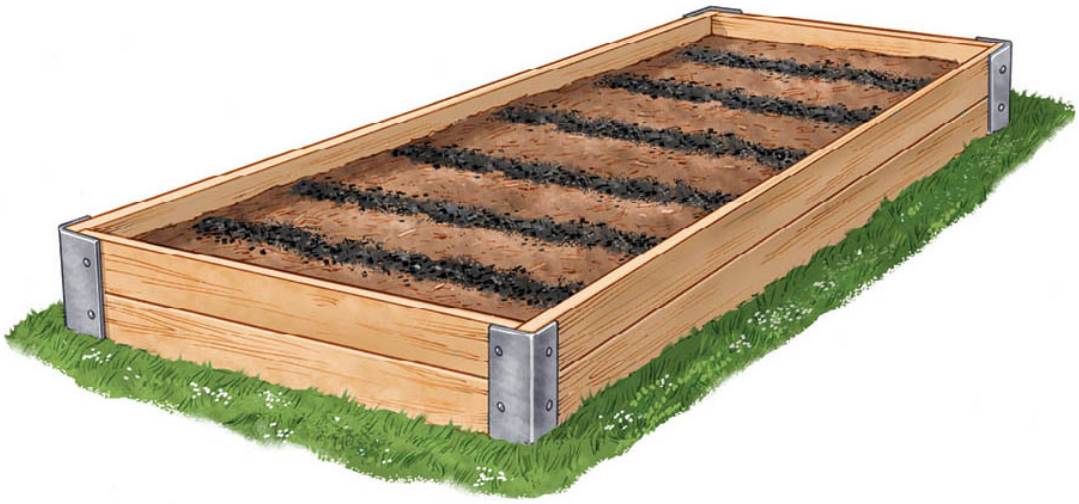
If you're only able to produce a small amount of biochar each season, consider adding it in bands over the course of five years. Crosshatching bands of biochar from one year to the next will ensure even coverage across the bed.

YEAR ONE

Make planting rows down the length of the bed, and use a 50-50 mixture of biochar and compost in 2-inch-wide strips just where the seeds or transplants will go.

YEAR TWO

Run your rows across the bed, again using the biochar-compost mixture in 2-inch wide strips right where the seedlings will go.

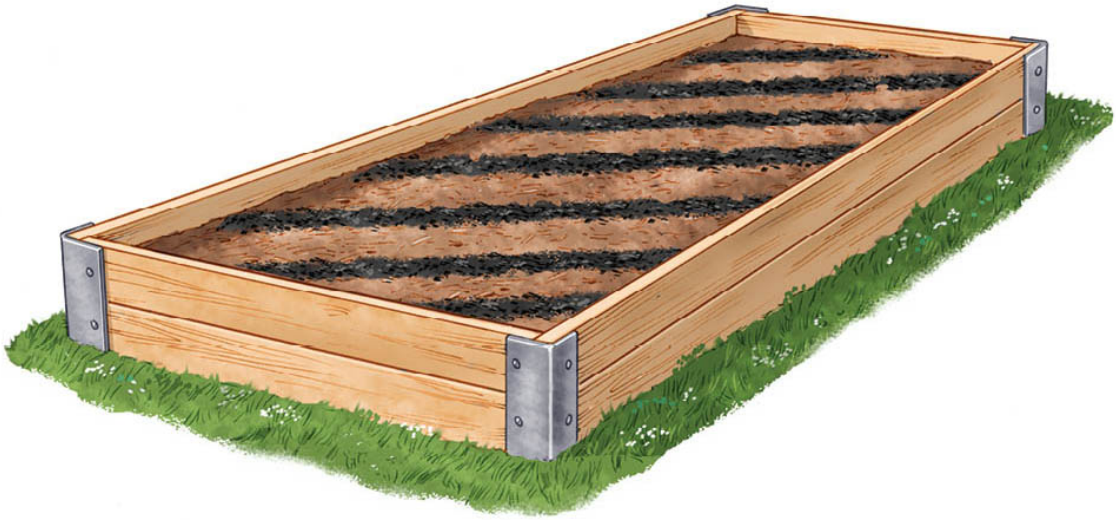


YEAR THREE

Make diagonal rows that run aslant the bed.

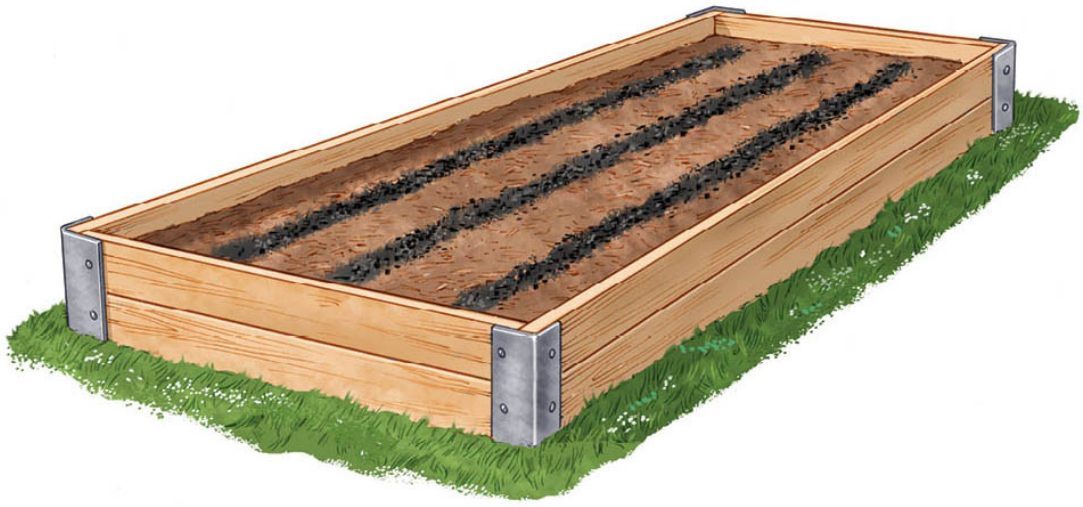
YEAR FOUR

Slant your rows in the opposite direction.



YEAR FIVE AND BEYOND

Repeat the process by going back to the vertical rows of year one.



What to Expect from Crop Yields

Some crops will respond to biochar more dramatically than others. In fact, the Ithaka Institute — a nonprofit research foundation with headquarters in Switzerland — did some remarkably thorough studies on this over a two-year period. More than 200 backyard gardeners took part in a trial that the Institute conducted. Each test garden had two 10-square-meter plots, one fertilized with compost and the second fertilized with the same compost but with biochar added. The plots were then planted with the same vegetables. Different gardeners trialed various vegetables.

By the end of the second year, evaluations of individual plots showed a wide range of results, even after the extreme results were eliminated. For example, some gardeners reported yields from the biochar-amended plots more than double those from the compost-only plots. Other

gardeners reported a negative impact on yield by the biochar-amended soils. The average for all tests, however, showed a 7.5 percent increase in yields.

“The most important outcome of the whole test,” reports the Ithaka Institute, “can be seen when looking at the results per plant family. Whereas Brassicaceae (cabbage family members), Cucurbitaceae (melon, squash, cucumber family members), and Apiaceae (umbelliferous family members like carrots, dill, and fennel) did particularly well, the opposite was true for Solanaceae (nightshade family members like tomatoes, eggplant, and potatoes). No trend in either direction was noticeable for legumes (peas, beans) or Asteraceae (lettuces).”

ABOVE: *Plants in the same families as cabbage, melon, fennel, and tomatoes respond very well to biochar-amended soil.*

sow a cover

CROP

One of the best things you can do for your garden soil is to sow it with a cover crop, preferably a legume with deep roots, in fall to overwinter, or in early spring to become green manure later in the growing season. Legumes like peas and beans are plants in the family Fabaceae, whose roots can be colonized by

nitrogen-fixing bacteria. Good leguminous cover crops include alfalfa, crimson clover, white clover, and hairy vetch — either planted alone or even better, all together. These so-called "green manure" crops are used to improve soil. Add inoculated biochar to garden soil before planting cover crops. The cover crops in consort with biochar will help stimulate soil life and are naturally better fertilizer than anything that comes out of a factory.

Cover crops can be planted in spring and turned under in late summer to fertilize fallow soil that year, or they can be planted in fall to winter over and emerge the next spring, when they can be turned under before crops are planted. They hold the soil together with their roots during driving winter rains that might otherwise wash away topsoil. Being legumes, they work in association with nitrogen-fixing soil microbes to add nitrogen that they take from the air. They also add organic carbon to the soil that they take from CO_2 and can make phosphorus better available to subsequent crops. And they attract beneficial insects if allowed to flower before being turned under. There are other cover crops suited to specific regions of the country; for example, grape farmers often plant fava beans in fall, which grow tall during wet winters and are then turned under the soil in the rows between vines in spring, fertilizing the soil and adding organic matter.

ABOVE: *Cover crops like white clover work with biochar to stimulate soil life.*

EPILOGUE

the promise of biochar

In addition to its ability to boost productivity in the garden, biochar offers a way to help mitigate climate change by sequestering carbon in the soil instead of releasing it into the atmosphere. Scientists estimate that if we could increase the amount of carbon stored in the world's soils by just four parts per thousand each year, we could sequester 100 percent of the carbon we currently add to the atmosphere annually.

Until recently, soil hasn't been a central focus in the idea of carbon-capture. The discovery of terra preta and the use of biochar can change that. If we can make the soil a carbon-sink, we'll discover a host of benefits that accompany carbon capture: better soil fertility, more erosion control, greater biodiversity in the soil leading to more functional soil ecologies, and other important physical effects on the soil.

Real progress toward carbon sequestration is being made by small-farm shareholders, indigenous peoples, and individuals and families on their land. For folks who till their own soil, climate change has direct effects as the earth warms, insects breed, seas rise, and storms become more severe. As we learned at the beginning of this book, it was the indigenous tribes of the Amazon Basin who, in some way that we still do not fully understand, created terra preta and turned the poor soils of the jungle into rich and yielding sources of food. The people who live with nature and learn from nature often know how to follow nature and do what is good for nature — which ultimately benefits other people.

That brings us to you — the gardener. What you do is incredibly important because in the aggregate, all of us working with biochar are making a real difference. If you and I do what we can, on our own plot of land in our own way, we can make for a more sustainable existence. When you use biochar in the garden, you are seeding fertility in the soil that will last far down the corridors of time, leaving a healthy source of soil and food for generations to come.

GLOSSARY

Absorb (verb): To take something in through pores or interstices.

Adsorb (verb): To hold (a gas, liquid, or dissolved substance) on a surface in a condensed layer.

Anion (noun): A negatively charged ion, especially the ion that migrates to an anode in electrolysis.

Biomass (noun): Plant or animal material, such as forestry by-products or agricultural waste, that is used as a fuel or energy source.

Cation (noun): An ion or group of ions having a positive charge and characteristically moving toward the negative electrode in electrolysis.

Compost (noun): A mixture of organic matter, as from leaves and manure, that has decayed or has been digested by organisms, used to improve soil structure and provide nutrients.

Feedstock (noun): Raw material or fuel required for an industrial process.

Humus (noun): A brown or black organic substance consisting of partially or wholly decayed vegetable or animal matter that

provides nutrients for plants and increases the ability of soil to retain water.

Hydrophilic (adj.): Having an affinity for water; readily absorbing or dissolving in water.

Hydrophobic (adj.): Repelling, tending not to combine with, or incapable of dissolving in water.

Laterite (noun): Any of a group of deposits consisting of residual insoluble deposits of ferric and aluminum oxides formed by weathering of rocks in tropical regions.

Phloem (noun): The tissue of vascular plants that conducts food produced by photosynthesis to all parts of the plant and consists of sieve elements, fibers, and parenchyma.

Pyrolysis (noun): Decomposition or transformation of a compound caused by heat.

Tubules (noun): Any small tubular structure, especially one in an animal or plant.

Xylem (noun): The tissue of vascular plants that conducts water and minerals, provides support, and consists of tracheary elements and parenchyma cells. Woody tissue is made of secondary xylem produced by the vascular cambium.

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METRIC CONVERSION CHARTS

To convert	to	multiply
inches	millimeters	inches by 25.4
inches	centimeters	inches by 2.54
inches	meters	inches by 0.0254
feet	meters	feet by 0.3048
yards	centimeters	yards by 91.44
yards	meters	yards by 0.9144

To convert	to	multiply
pounds	kilograms	pounds by 0.45

To convert	to	
Fahrenheit	Celsius	subtract 32 from Fahrenheit temperature, multiply by 5, then divide by 9

To convert	to	multiply
tablespoons	milliliters	tablespoons by 14.79
cups	milliliters	cups by 236.59
cups	liters	cups by 0.24
pints	liters	pints by 0.473
quarts	liters	quarts by 0.946
gallons	liters	gallons by 3.785

INDEX

Page numbers in *italic* indicate drawings and photographs; page numbers in **bold** indicate tables and charts.

A

absorb, adsorb vs., 28, *28*
activated charcoal, 30, *30*, 52
adsorbent spaces, 27
African black earths, 16
aggregation, *22*, 97
agricultural residues, 39
alkalinity, 35
Amazon rainforest, soils of, 10–15, *11*, *12*
ammonia, 42–43
ammonium, 36, 43
ammonium fertilizer, 36
angle grinders, *67*
anions, 33–34
annual schedule, 82
Apiaceae, 116
applications. *See* uses of biochar
arsenic, 38
Asteraceae, 116
Azomite, 103

B

bagging, 83
Baker, Norm, 64, 88–89, *89*
Baker, Peggy, 88–89, *89*
bedrock, *11*
benefits of biochar
    buffering effects of toxic elements, 38
    cation exchange capacity increase, 36
    greenhouse gas decrease, 37–38
    housing for microbes, 27, *29*
    increased nutrient availability, 33–34
    overview of, 27, 39, 119–120
    reservoir for water and nutrients, 28–29
The Biochar Revolution (Baker and Taylor), 64
biodiversity, 22
biomass, 23
bits, *67*
black lung disease, 48
bones, 81
Brassicaceae, 116
briquettes, 31, *31*
buffering capacity, 38
burn piles, 56
burn pits, making biochar in, 55–63
buying biochar, 84

C

cadmium, 38
calcitic limestone, 110
calcium, **85**, 103
Can-O-Worms, 98–99
cans, metal, 79–81
capillary action, 28
carbon, biochar as source of, 24
carbon-negative living, 88
carbon sequestration, 37–39, 119–120
carcinogenic compounds, 50
castings, 26, 96–99
cation exchange capacity (CEC), 33, 34, 36, 48, 93
cations, 33–34
CEC. *See* cation exchange capacity
charcoal, types of, 30–31, *30*, *31*
chickens, 100–101
chiefdoms, 15
chromium, 38
climate change, 119–120
co-composting, 94–95
combustor barrels, 69, *69*
communication, plants and, 21–22
compost, 102, *102*
compost tea, 26, 101, *101*
copper, 38
cornstalks, 49
cover crops, 117–118

crop yields, 116
crushing, 83, *83*
cucumbers, *32*, 116
Cucurbitaceae, 116

D

decomposition, 37, 93
definition of biochar, 31, *31*
discovery of biochar, 13–14
diseases, 15
dolomitic limestone, 110
doneness, assessing, 63
Donnelly, Art, 88
dousing, 61
drainage, 55, 111
drills, *67*
drying process, 63

E

electron transfer, 40–43
Europeans in history of biochar use, 14–15

F

Fabaceae, 117
feeding of biochar, 100
feedstock
analysis of biochar produced be different, **51**
defined, 23
loading into burn pit, 58, *58*
natural wildfires and, 52
selecting, 48
small, dry wood, 50, 53
types of, *48*
feedstock barrels, 68, *68*, 73
fermentation, 96–97
fertilizers, 43, 106, 112
flour, 96–97, 103

G

garden beds
cover crops and, 117–118
using biochar in, 106, 113, *114–115*, 116
gases, 23, 26. *See also* greenhouse gases
global warming, 39
gloves, welder's, *46*, 47
grading, *86*, 87
greenhouse gases, 37–39, 119–120
greensand, 103
green wood, 50

H

Haber-Bosch process, 42
hardwood, 48, *48*, 53
humus, *11*, 93
hydrophilic charcoal, 26, 95
hydrophobicity, 26, 95
hyphae, 97

I

Inca Empire, 14
inoculation
    chickens and, 100–101
    with finished compost, 102
    methods for, 94–97
    mineral boosts and, 103
    overview of, 91
    reasons for, 92–93
    soaking for, 101
    spot-feeding plants and, 112
    water and, 95
    worms and, 96–97, 98–99
intestines, biochar and, 100
iron, 33, 36
Ithaka Institute, 116

J

jigsaws, *67*

L

laterization, 10, *11*
leached zone, *11*
lead, 38
legumes, 42, 116, 117–118
Lehmann, Johannes, 41
limestone applications, 108–110, **109**
liquid amendments, 112

M

mafic igneous bedrock, *11*
magnesium, 33, 36, **85**, 103, 110
manganese, 33, 38, 103
manure, 48, **51**, 96, 100–101
maple, 53
maple chip biochar, **85**
mercury, 38
metal, tools for cutting, *67*
methane, 38
micronized rock powder, 103

microorganisms. *See also* inoculation
degradation by, 24
electron transfer and, 40–43
inoculation with, 26
structural support for, 27
middens, 13
mid-grade, *86*, 87
mineral nutrient content, **85**, 103
moisture content, 50
molybdenum, 42–43

N

Native Americans, 12–13
nitrate, 43
nitrates, 36
nitrite, 43
nitrogen, 42–43, 106
nitrogen, potentially mineralizable, 36
nitrogen-fixing bacteria, 42
nitrous oxide, 38
nutrients
biochar as reservoir for, 28–29, 33
improving plants' ability to obtain, 33–34
pH and, 107

O

oak, 53
Orellana, Francisco de, 14–15
origins of biochar use, 9–13

P

peanut shells, 48
perc tests, 55, 111
pH
    adjusting, 108, **109**
    changes in, 35, *35*
    determining, 107
    feedstock selection and, 53
    of fresh biochar, 26
    inoculation and, 93
    testing, 108
    using biochar and, 107–110, **109**
phloem, 24, *25*, 27
phosphate, 33
phosphorus, 33, 36, **85**, 103
photosynthesis, 39
pine chips, **51**
Pizarro, Francisco, 14
potassium, 33, **85**, 103
poultry litter, **51**
premium grade, *86*, 87

pyrolization, 30
pyrolized organic matter, defined, 13, 23
pyrolysis process
    activated charcoal and, 30
    in burn pit, 59–60
    charcoal briquettes, biochar and, 31
    methane emissions and, 38
    overview of, 23
    in TLUD, 75–76

Q

quenching barrels, 72, 76–77
Quito, Ecuador, 14

R

rainforests, 10–15, *11*, *12*
rakes, steel-tined, *46*, 47
raking, 83
Read, Peter, 23
reciprocating saws, *67*
red wigglers, 98
regular grade, *86*, 87
rhizobia, 42
rock phosphate, 103

rock powder, 103
roots, cross-section of, *25*

S

safety
    burn piles and, 56
    equipment for, *46*
    feedstock selection and, 49, 50
    micronized rock powder and, 103
    overview of, 47
    working with metal and, 67
San Juan Islands (Washington), 36
schedule, yearly, 82
SeaChar, 88
selecting biochar, 84–87, **85**, *86*
sequestration, 37–39, 119–120
shavings, *48*
slash-and-burn agriculture, 10, 15
smallpox, 15
smoke, 50, 56
softwood, 48, *48*
soil carbon sequestration, 37–39, 119–120
soil properties, burn pits and, 55
Solanaceae, 116
Spanish settlers, 15
stacks, 71, *71*
stems, cross-section of, *25*

straw, 48, *48*
structure of biochar, 24, *25*
sulfur, **85**, 108–110, **109**
Sun, Tianran, 40–41
surface tension, 28
swine solids, **51**
switchgrass, **51**
symbiotic relationships, 93

T

Taylor, Paul, 64
terra preta soils, *11*, *12*, 13–15, 24, 52, 88
Top Lit Up-Draft (TLUD) stoves
    building, 64–72
    images of, *64*, *72*
    large scale use of, 82
    operating, 73–78
    overview of, 23, 47
toxic elements, buffering effects of, 38
tubules, 27

U

University of Washington School of Environmental and Forest Sciences, 36

uses of biochar
with cover crops, 117–118
for drainage improvement, 111
in garden beds, 106, 113, *114–115*, 116
overview of, 105–106
pH and, 107–110, **109**
spot-feeding plants, 112

V

vinegar, wood, 26

W

water, 28–29, 95
white ash, 63
wildfires, natural, 52
wood chips, *48*, 50, **51**, 82
wood vinegar, 26
Woolf, Dominic, 38
worm castings, 26, 96–99

X

xylem, 24, *25*, 27

Z

zinc, 36, 38, 103

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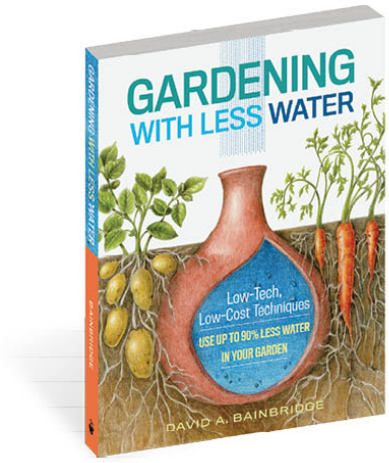

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Stu Campbell

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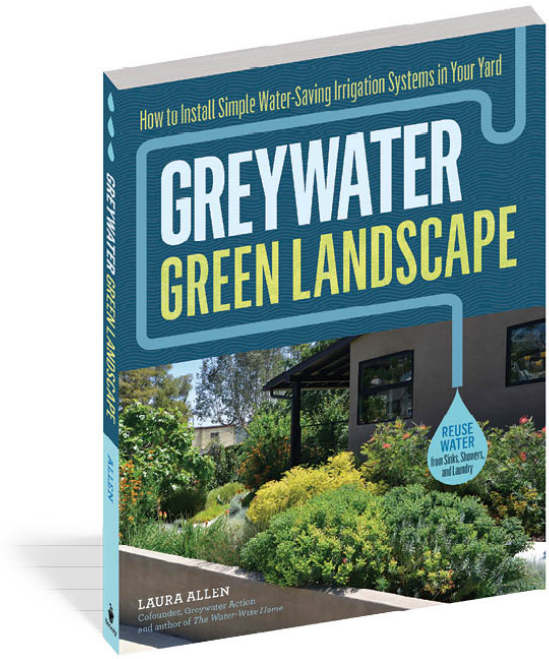
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LAURA ALLEN
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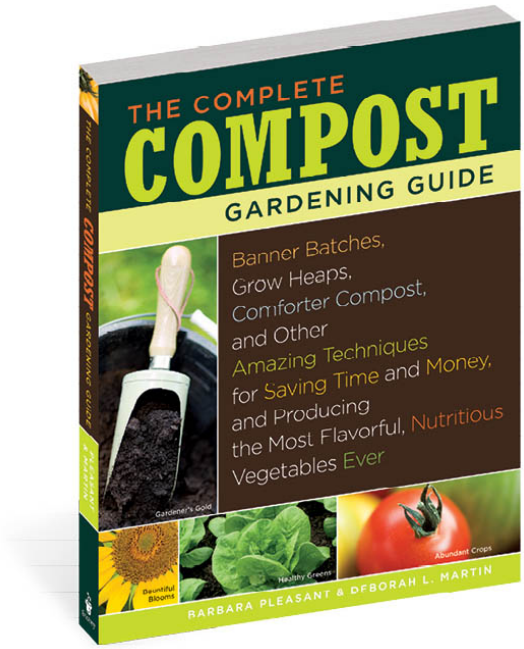
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